Quentin ARNAUD

Direct dark matter search
with
New **E**xperiment **W**ith **S**pheres

NEWS-LSM : WIMP search Results with Sedine

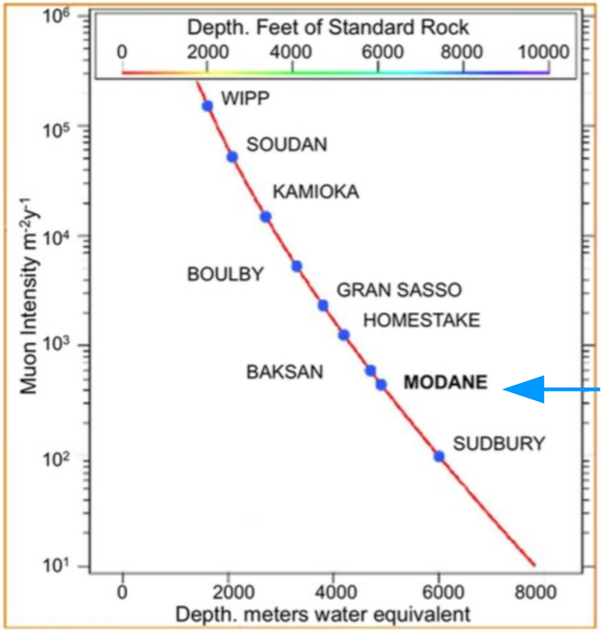
&

NEWS-SNO Projections

06/12/2016

3rd Berkeley Workshop on the Direct detection of Dark Matter

NEWS-LSM Experiment Setup

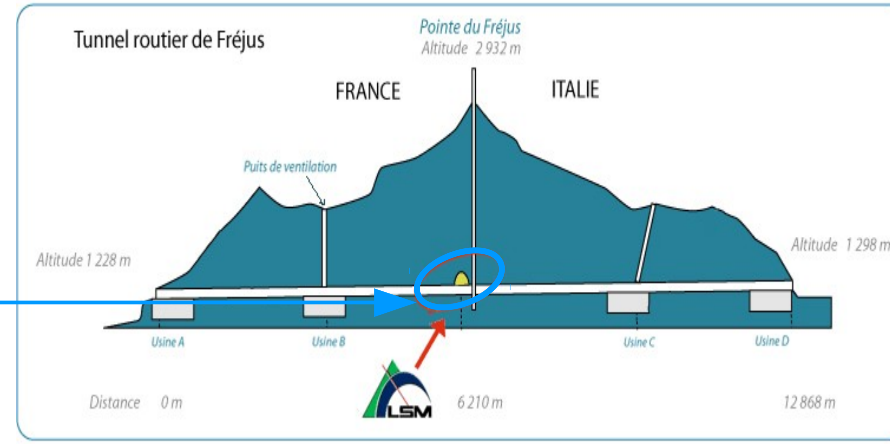


surface
$10^6\,\mu/m^2/day$

Muon flux

4800 mwe
$5\,\mu/m^2/day$

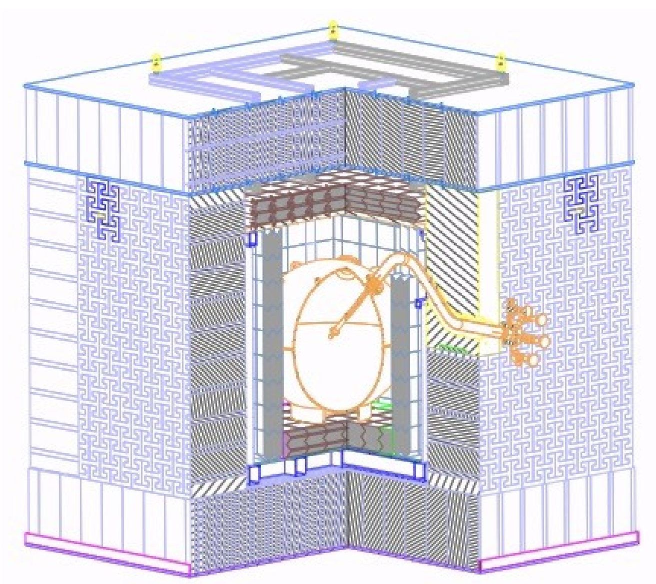
Laboratore Souterrain de Modane



Sedine Data taking conditions

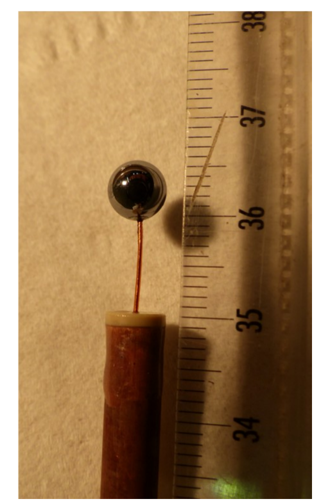
42 days of exposure with **Neon**+0.7 % **CH_4** @ **3 bars**

~300g sensitive mass



Shieldings
30 cm PE, **10 cm Pb**, [**3-7**] **cm Cu**

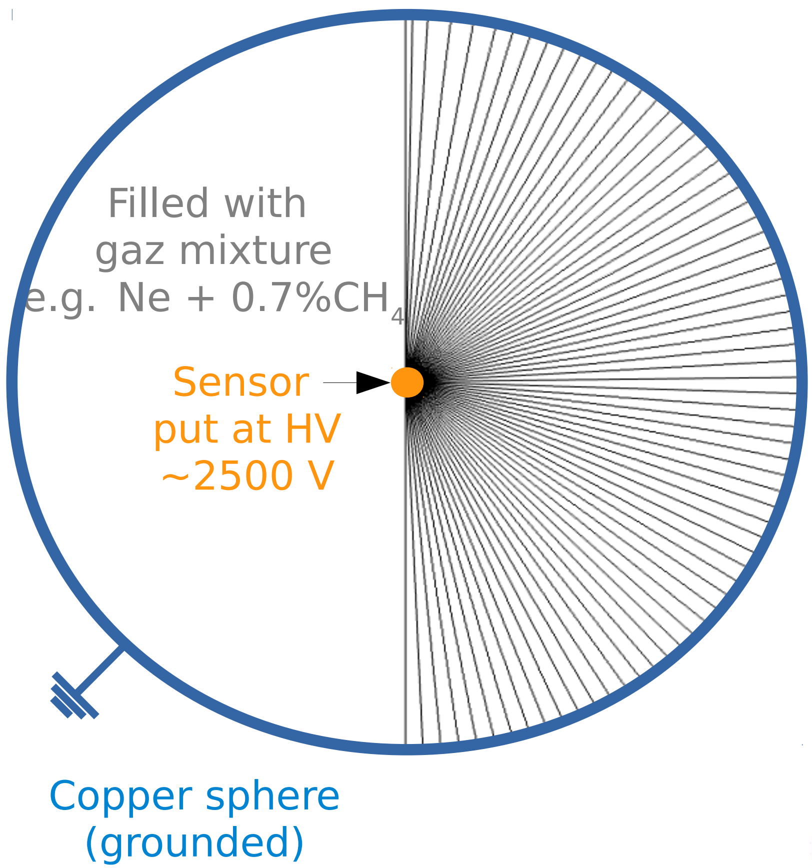
Vessel
60 cm Ø NOSV Copper



Sensor
6 mm Ø

Designed for low-mass WIMP search

Operated in sealed mode



Low threshold ~50eV$_{ee}$

(sensitivity to single electrons)

High gain arrising from

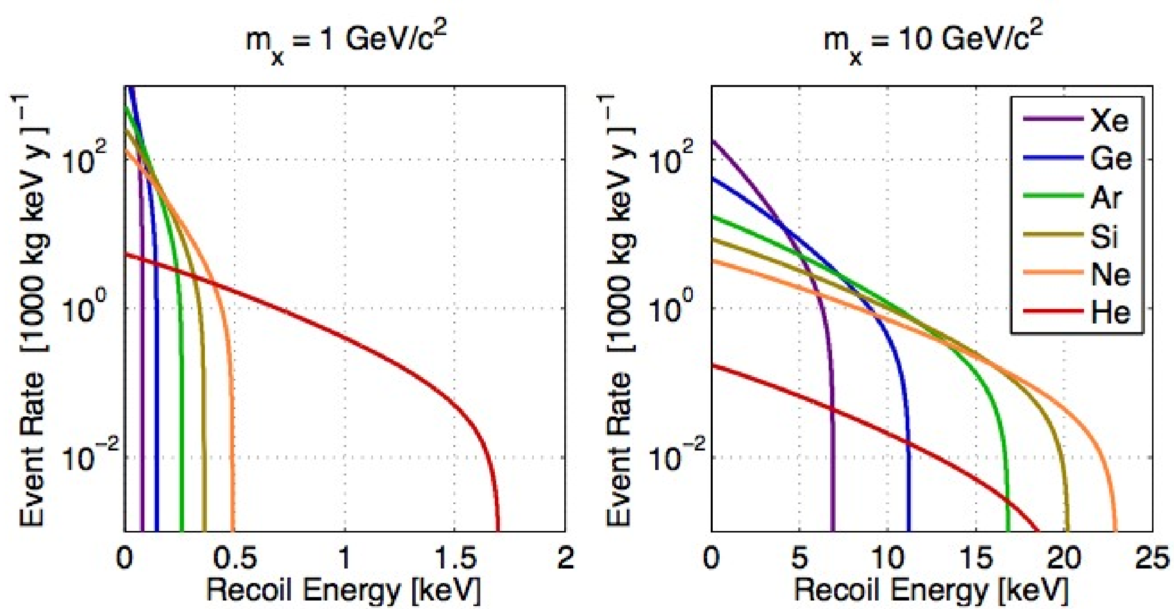
$$E(r) \propto \frac{1}{r^2}$$

And Low Capacitance

(doesn't depend on the size of the sphere)

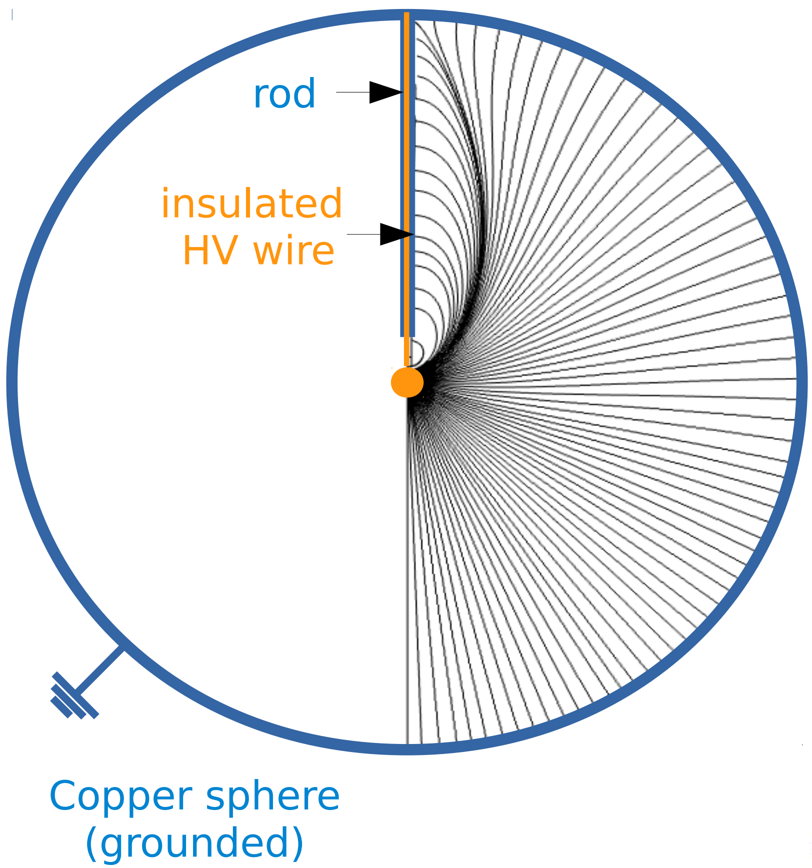
$$C = \frac{4\pi\epsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi\epsilon r_{sensor} \approx 0.3\,\mathrm{pF}$$

Light Target



Designed for low-mass WIMP search

Operated in sealed mode



Low threshold ~50eV$_{ee}$

(sensitivity to single electrons)

High gain arrising from

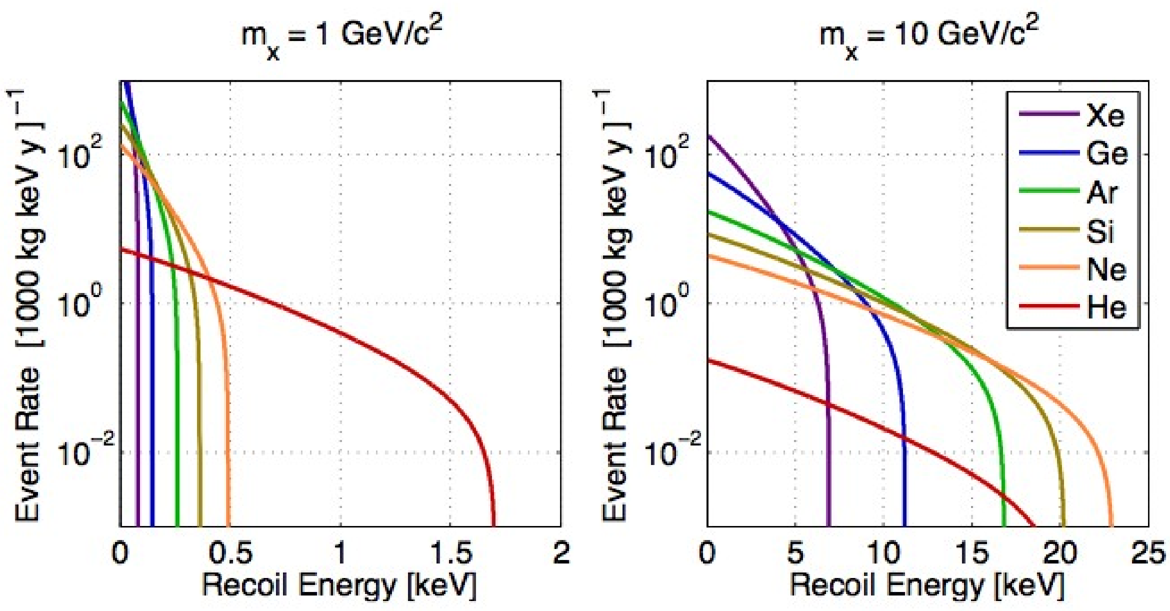
$$E(r) \propto \frac{1}{r^2}$$

And Low Capacitance

(doesn't depend on the size of the sphere)

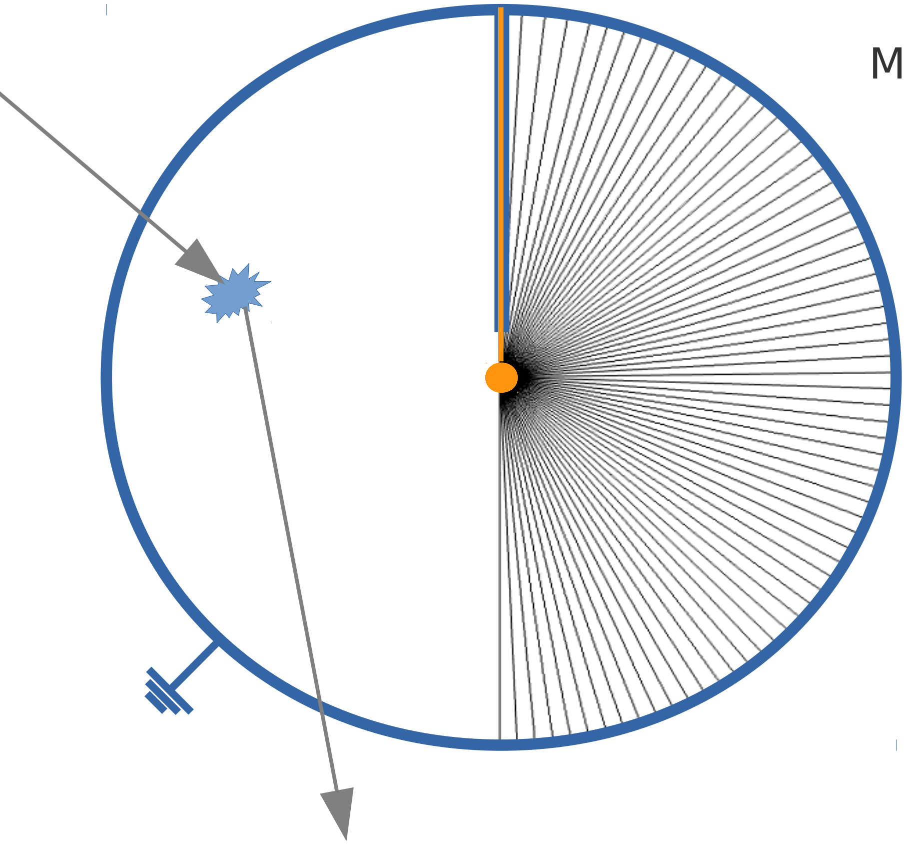
$$C = \frac{4\pi\epsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi\epsilon r_{sensor} \approx 0.3\,\mathrm{pF}$$

Light Target



Operating Principle

Following an energy deposit within the target gas :



Primary Ionisation

Mean number of primary electrons created : $<N> = \frac{E_R}{\epsilon_j}$

With Neon : $\epsilon_\gamma = 36\ \mathrm{eV}$ $\epsilon_n = \frac{\epsilon_\gamma}{Q(E_R)} \approx 5\,\epsilon_\gamma$

Drift of the electrons toward the sensor

Typical drift time surface → sensor : ~500 µs

Avalanche Process

Each primary electron leads in average to 3000 secondary ionisations

Signal Formation

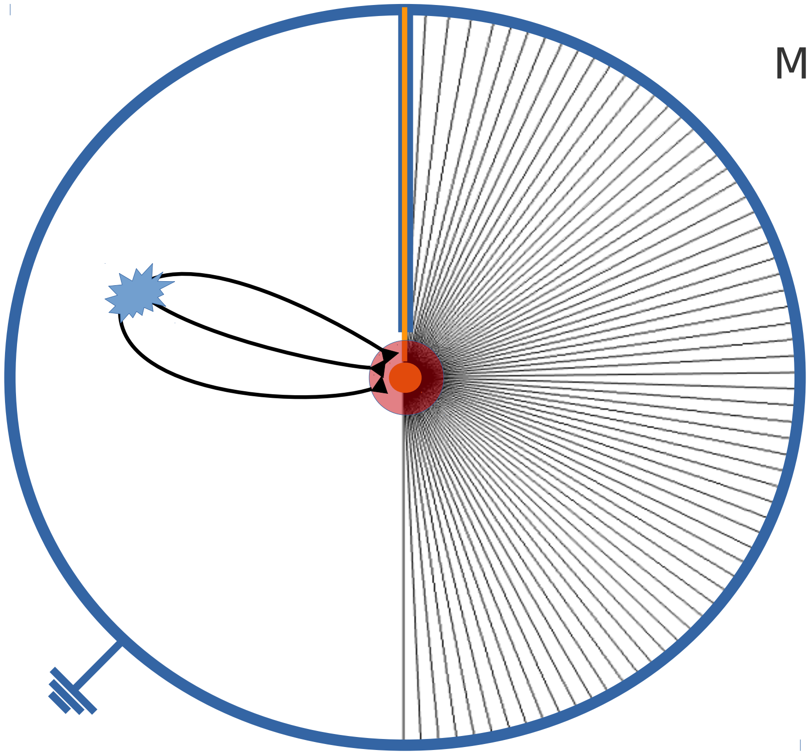
Current induced by secondary Ions drifting toward the ground

Signal readout with a charge amplifier

(RC=46 **µs**)

Operating Principle

Following an energy deposit within the target gas :



Primary Ionisation

Mean number of primary electrons created : $<\mathrm{N}> = \frac{E_R}{\epsilon_j}$

With Neon : $\epsilon_\gamma = 36\ \mathrm{eV}$ $\epsilon_n = \frac{\epsilon_\gamma}{Q(E_R)} \approx 5\,\epsilon_\gamma$

Drift of the electrons toward the sensor

Typical drift time surface → sensor : ~500 µs

Avalanche Process

Each primary electron leads in average to 3000 secondary ionisations

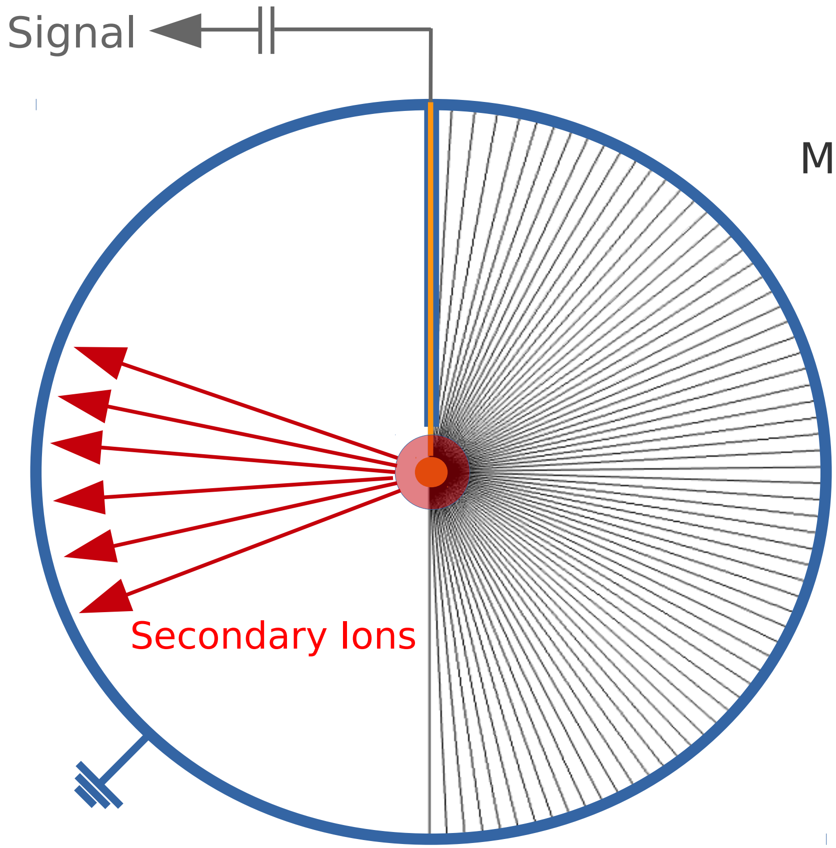
Signal Formation

Current induced by secondary Ions drifting toward the ground

Signal readout with a charge amplifier

(RC=46 **µs**)

Operating Principle



Primary Ionisation

Mean number of primary electrons created : $<N> = \frac{E_R}{\epsilon_j}$

With Neon : $\epsilon_\gamma = 36\ \text{eV}$ $\epsilon_n = \frac{\epsilon_\gamma}{Q(E_R)} \approx 5\,\epsilon_\gamma$

Drift of the electrons toward the sensor

Typical drift time surface → sensor : ~500 µs

Avalanche Process

Each primary electron leads in average to 3000 secondary ionisations

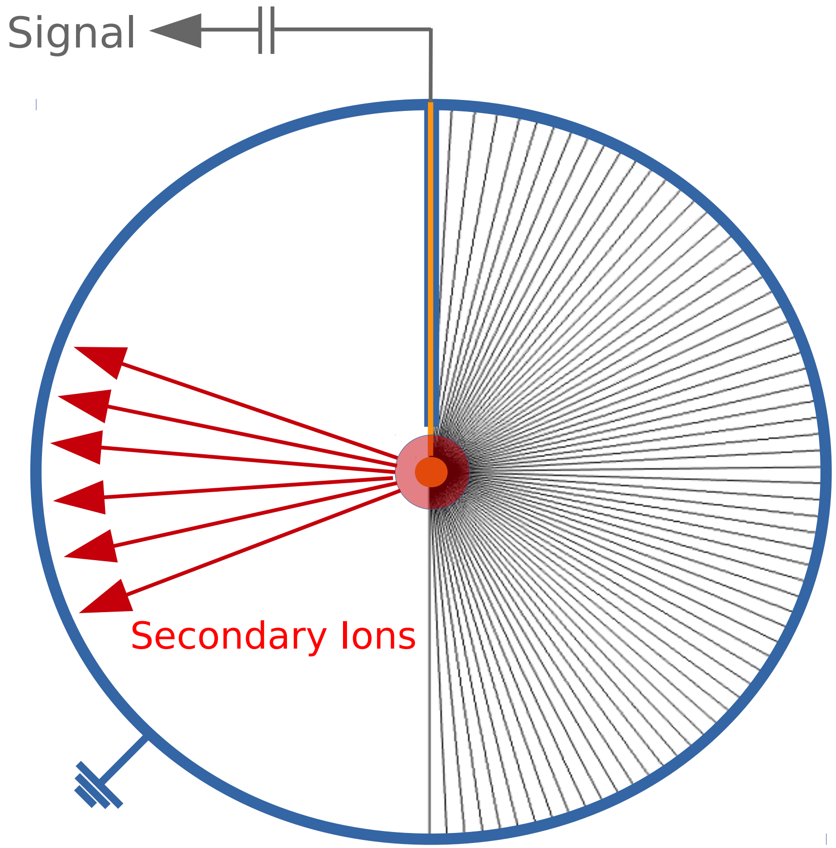
Signal Formation

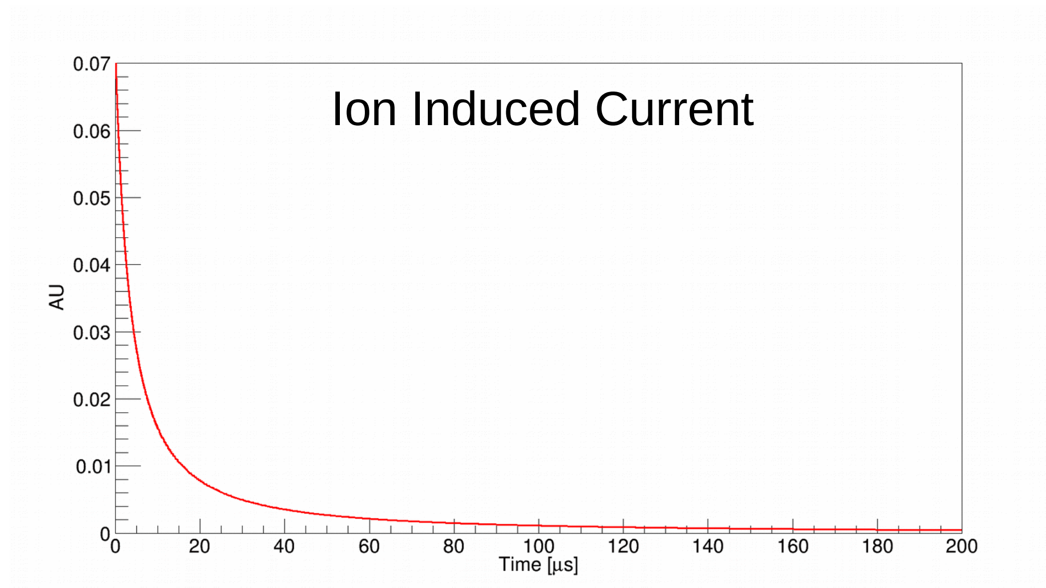
Current induced by secondary Ions drifting toward the ground

Signal readout with a charge amplifier

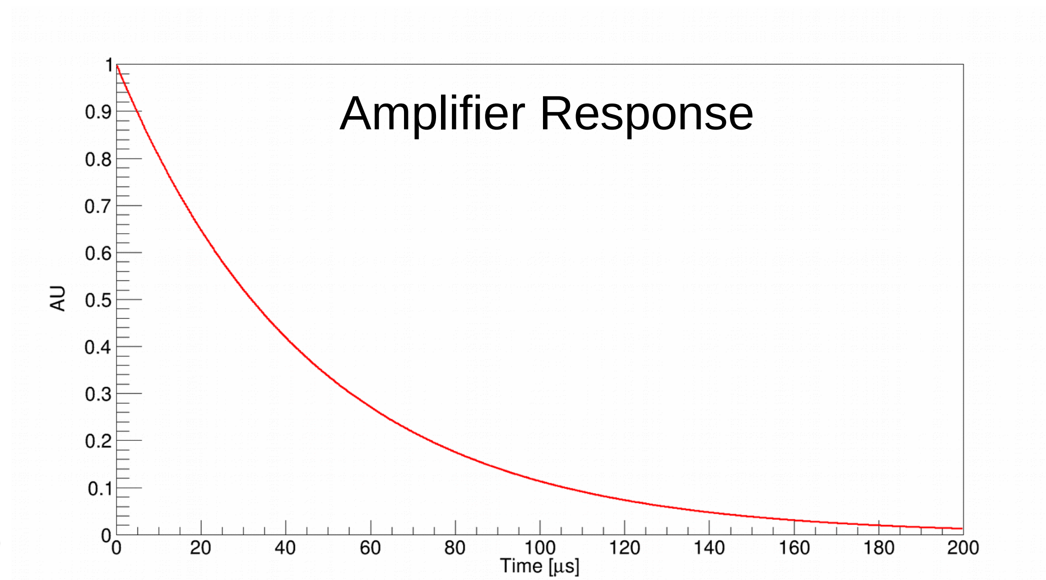
(RC=46 **µs**)

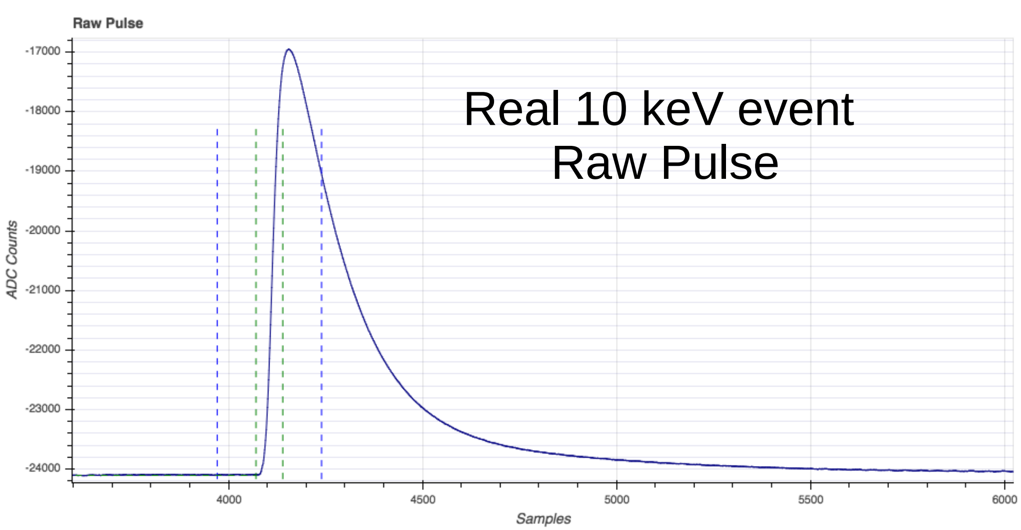
Operating Principle & Pulse Treatment



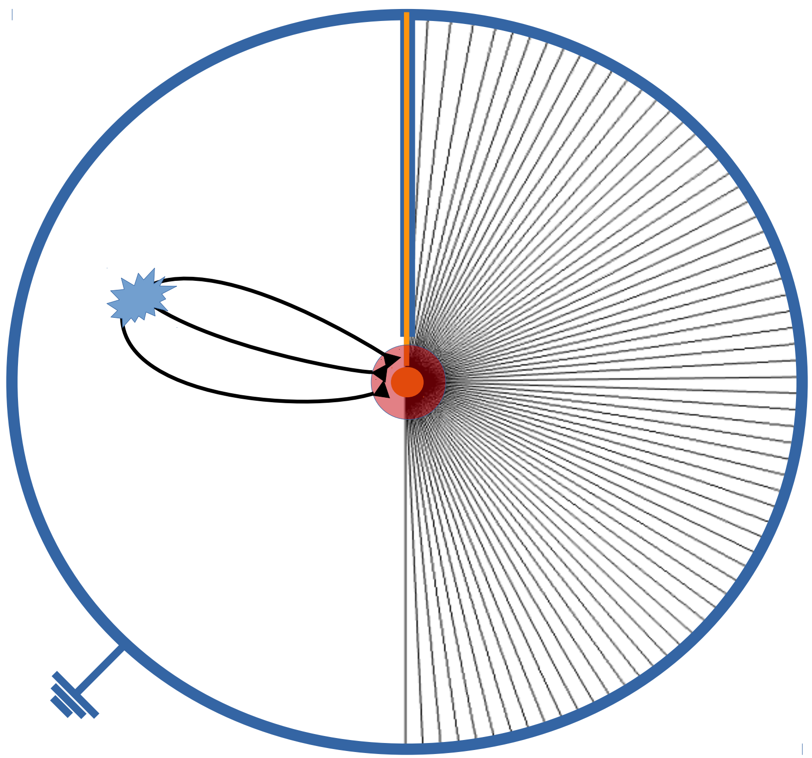


$\otimes$





Operating Principle & Pulse Treatment



Drift of the electrons toward the sensor

Typical drift time surface → sensor

(500 ± 20) µs

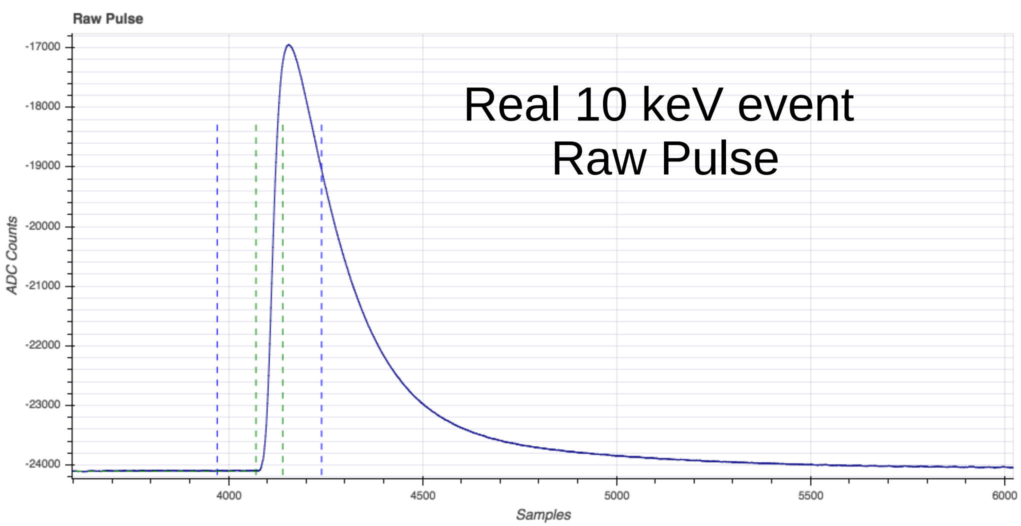
Dispersions in the arrival time of primary electrons due to diffusion

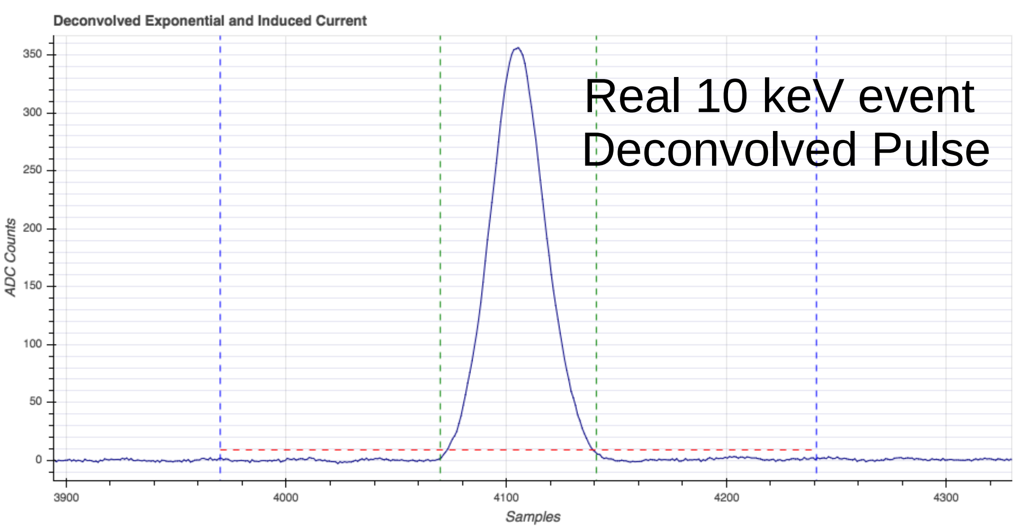
well modelized by a Gaussian distribution

$$\sigma(\boldsymbol{r}) = \sigma(r_{max})\left(\frac{\boldsymbol{r}}{r_{max}}\right)^3$$

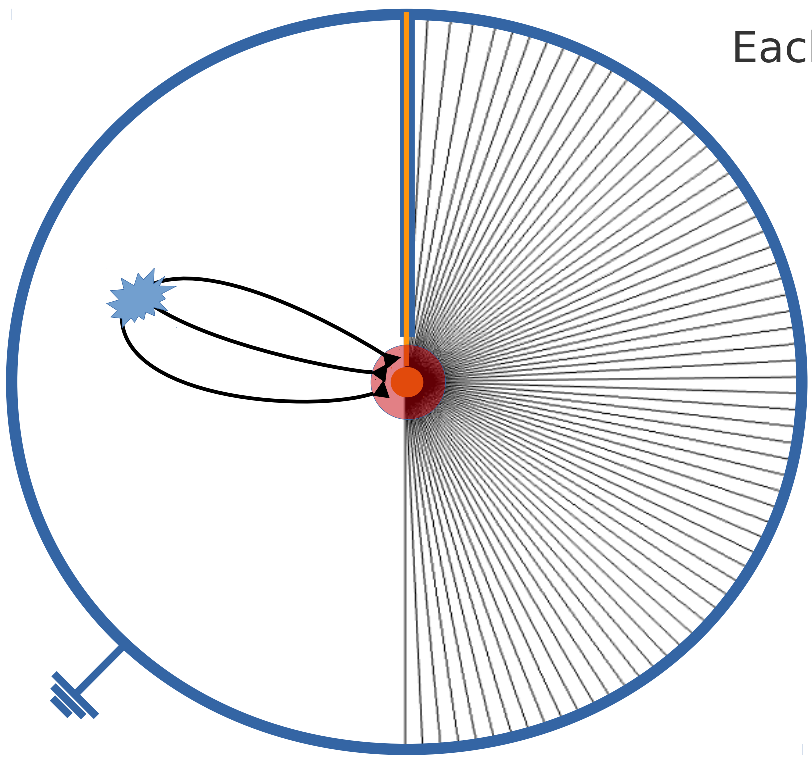
The further away the energy deposit
The larger the diffusion time

Fiducialisation



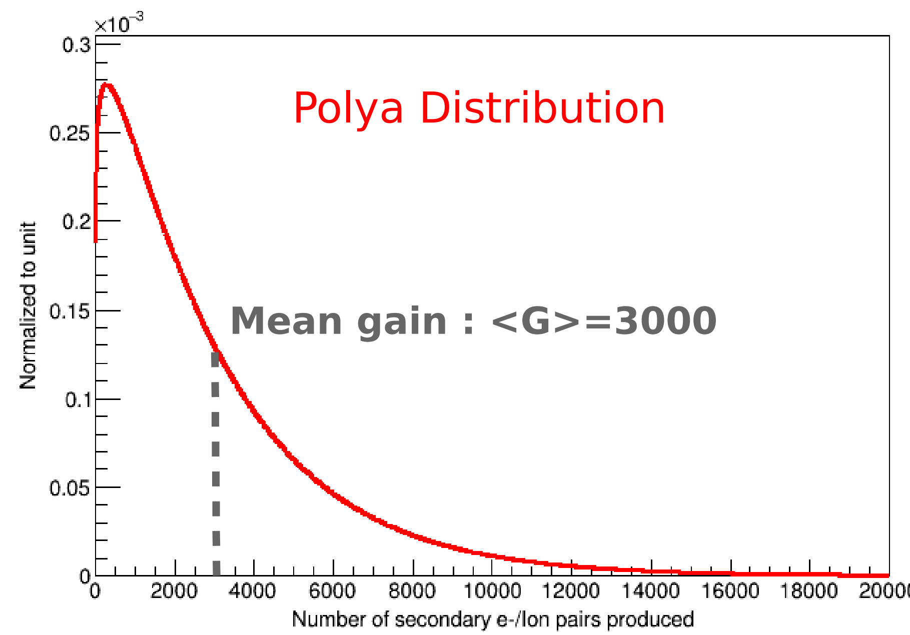


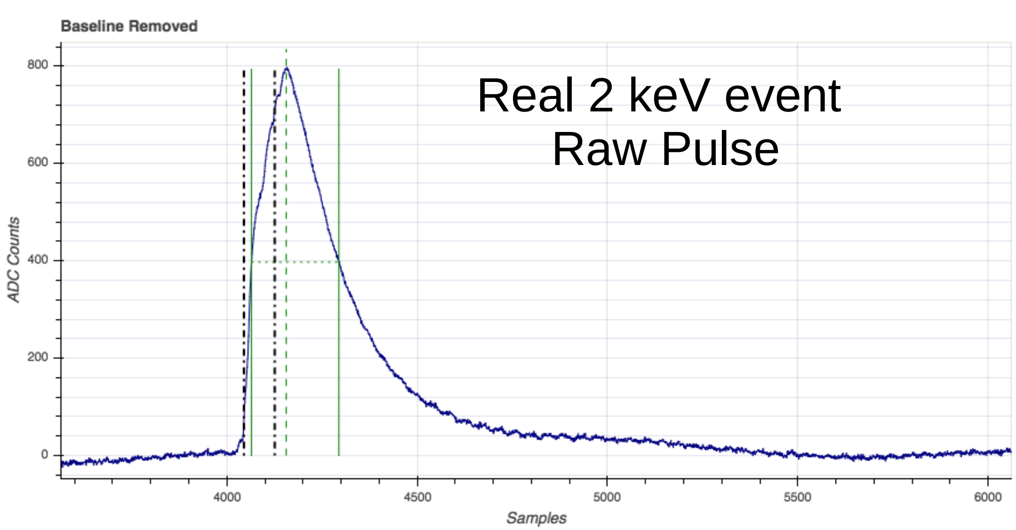
Operating Principle & Pulse Treatment

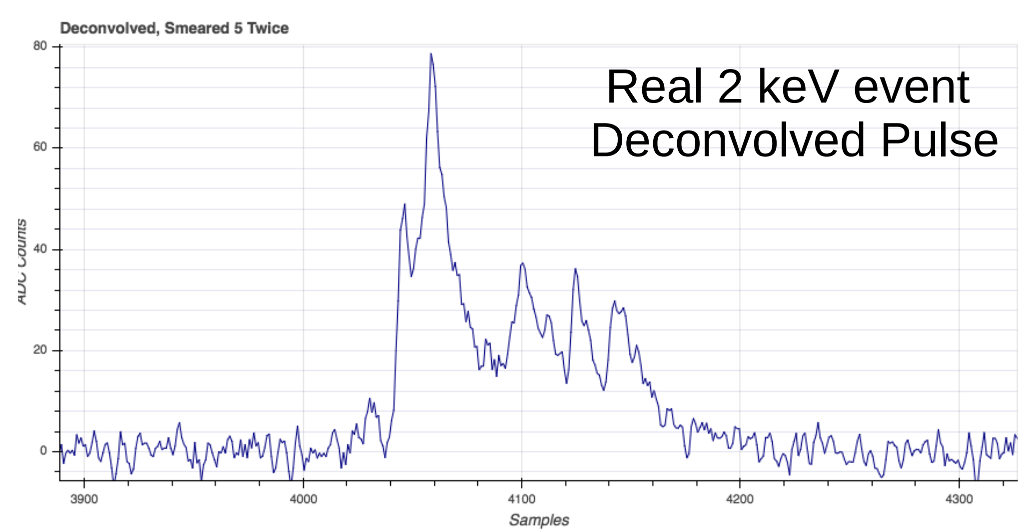


Avalanche Process

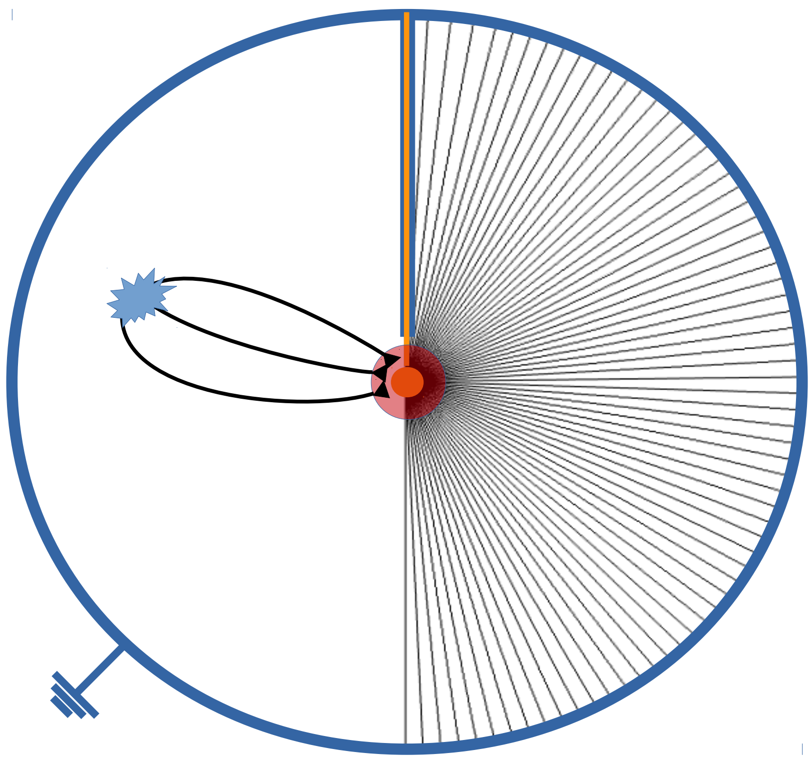
Each primary electron → <Ns>=3000 secondary ionisations





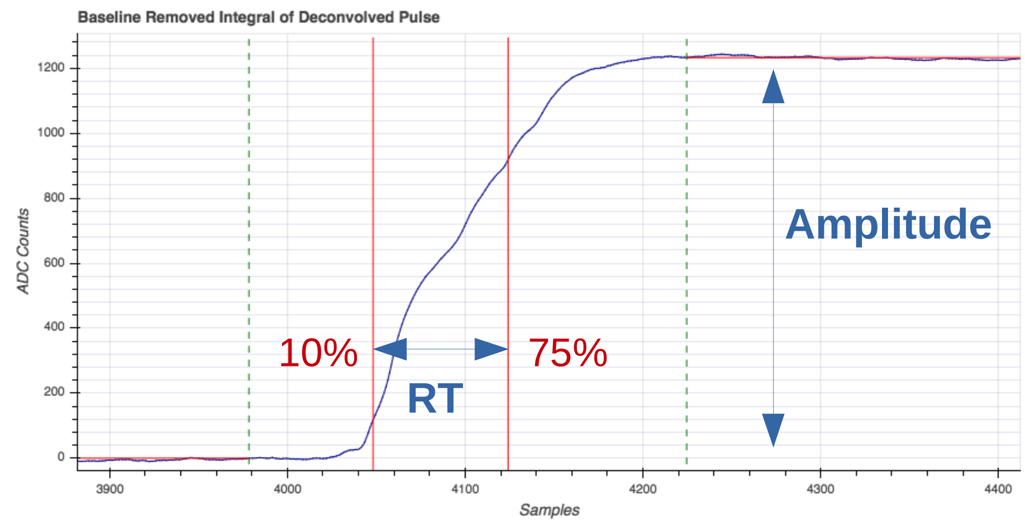


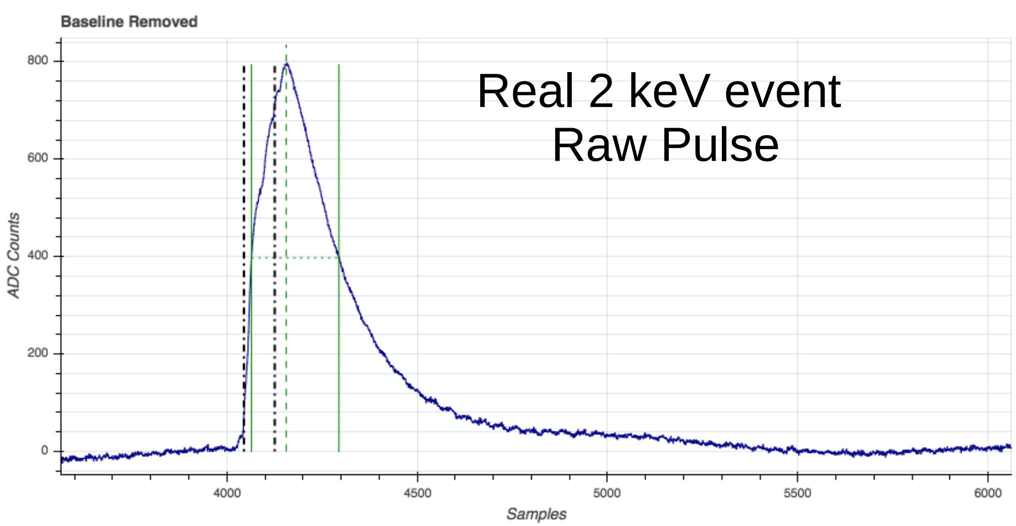
Operating Principle & Pulse Treatment

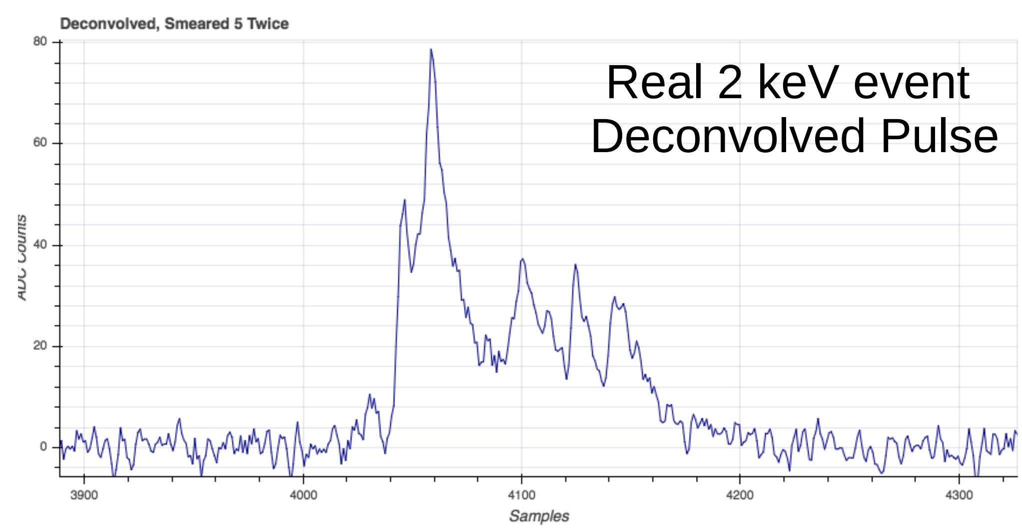


Energy and Diffusion Estimators

Real 2 keV event
Cumulative of Deconvolved Pulse







Data Analysis : Simulations

Arrival time of primary electrons drawn from a Gaussian distribution with $\sigma(\boldsymbol{r}) = \sigma(r_{max})\left(\frac{\boldsymbol{r}}{r_{max}}\right)^3$

+

Number of secondary electrons drawn from the polya Distribution

+

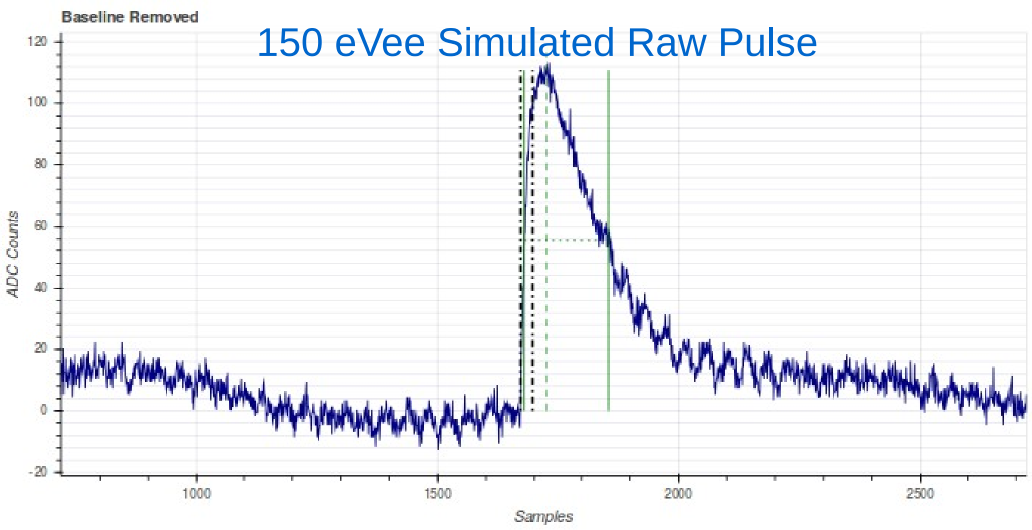
Detector Response analyticaly known (Ion Induced current **X** Amplifier response)

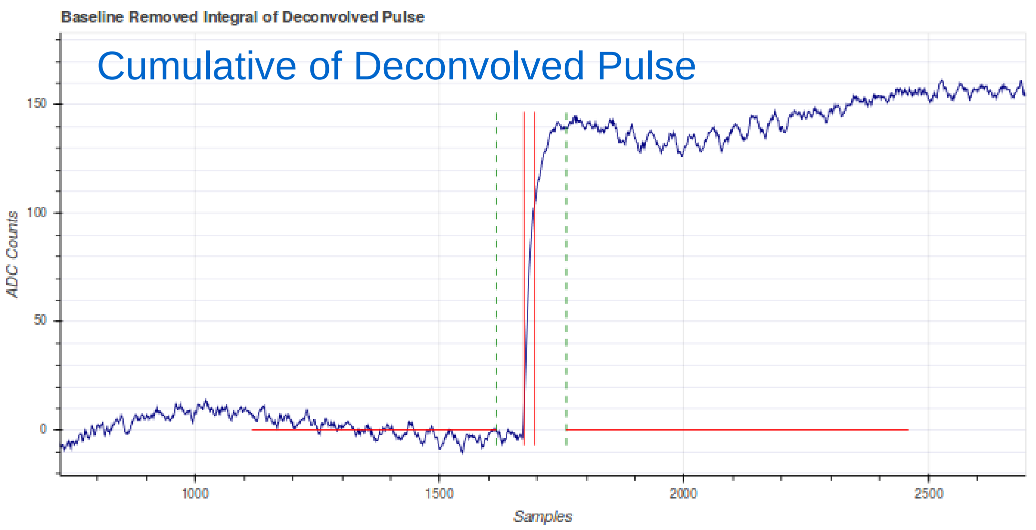
+

Simulated pulses are added to noise templates taken from the pretraces of a real pulses

+

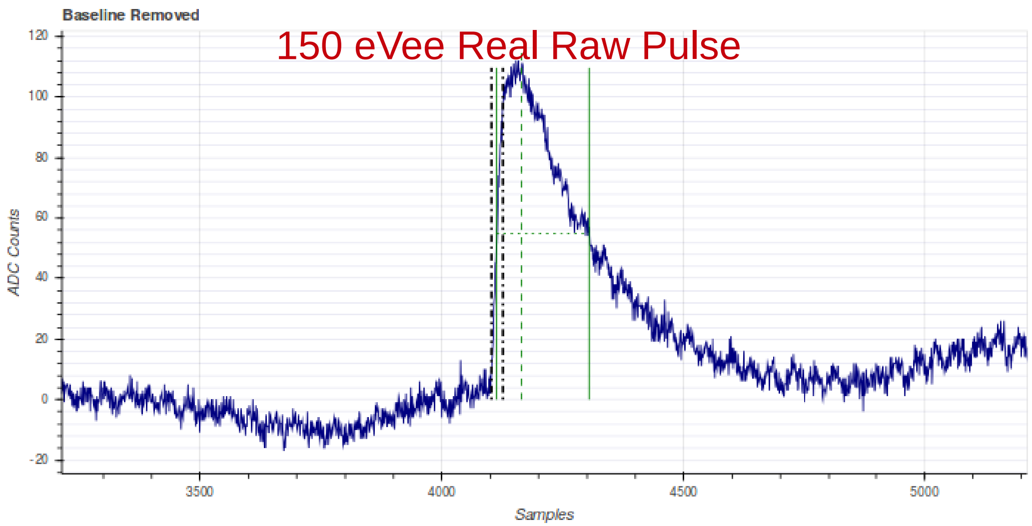
Same processing than for real pulses

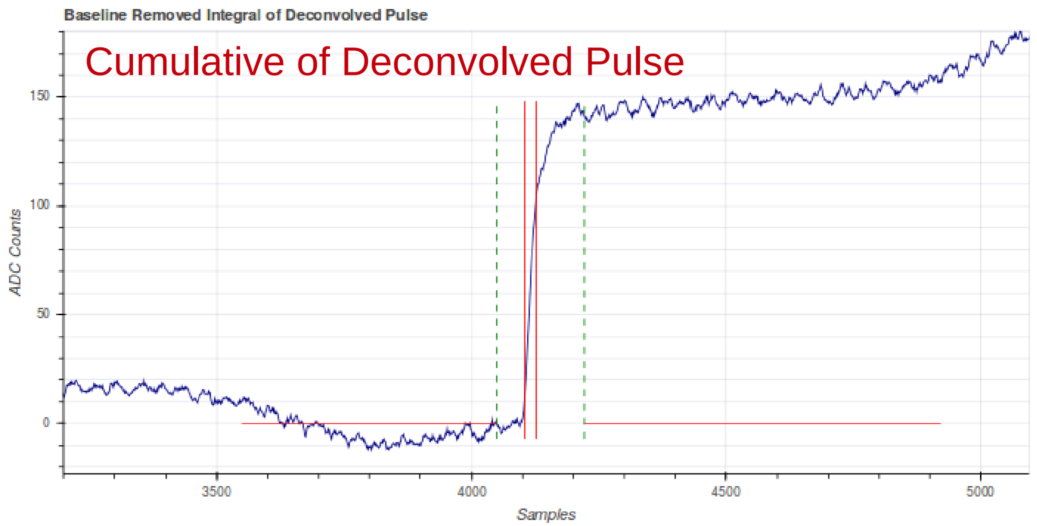




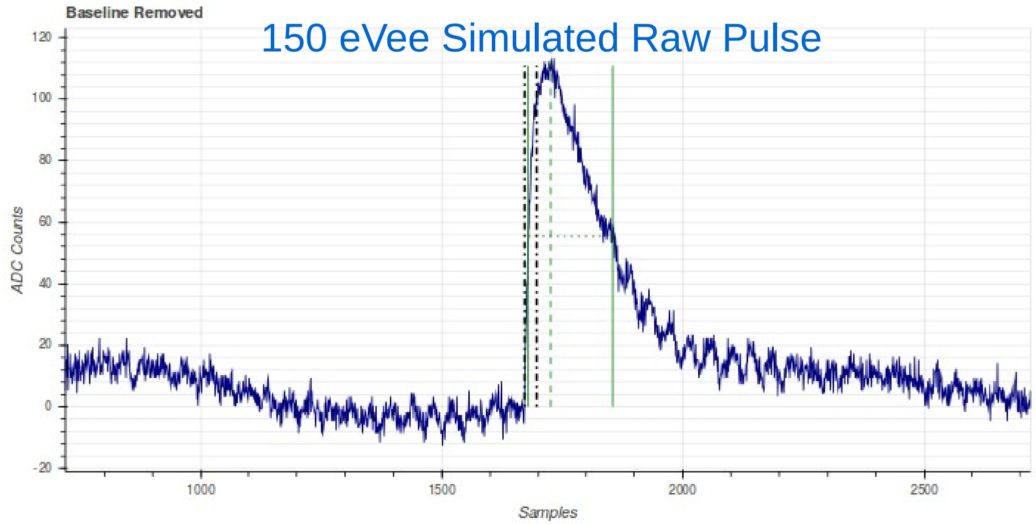
Data Analysis : Simulations

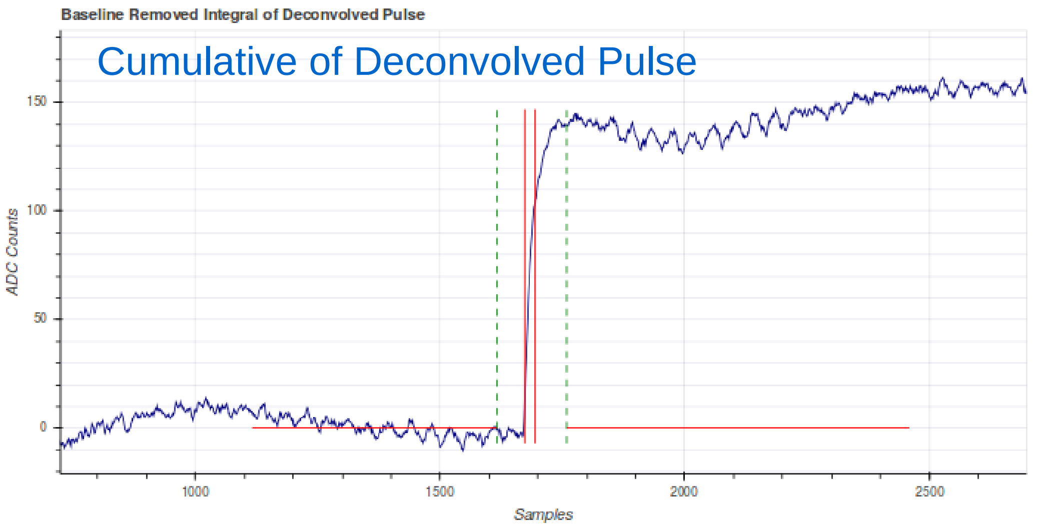
Data





Simulation

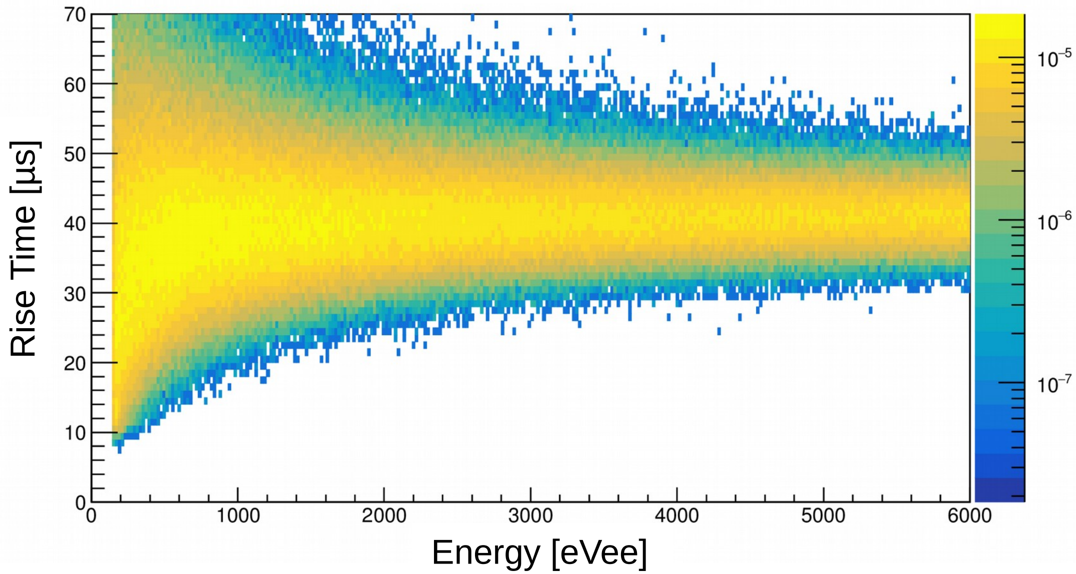




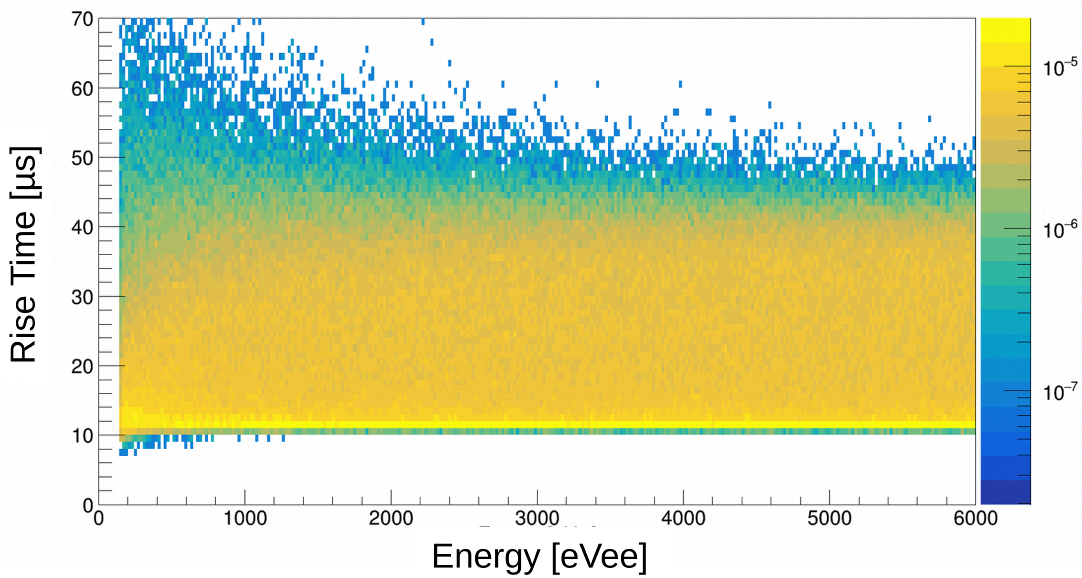
Data Analysis : Simulations

Background PDFs

Surface events

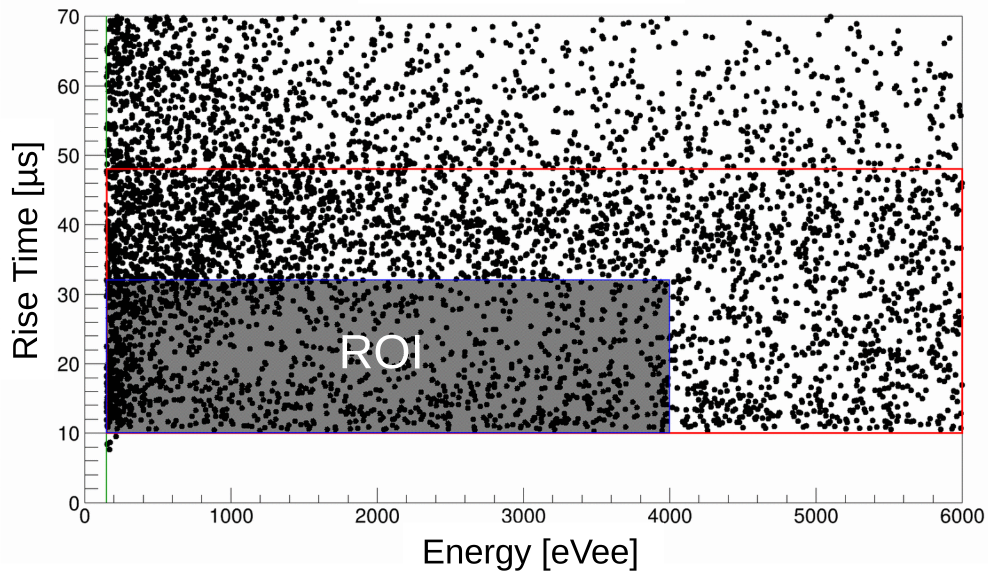


Volume events



Sedine data

WIMP search run



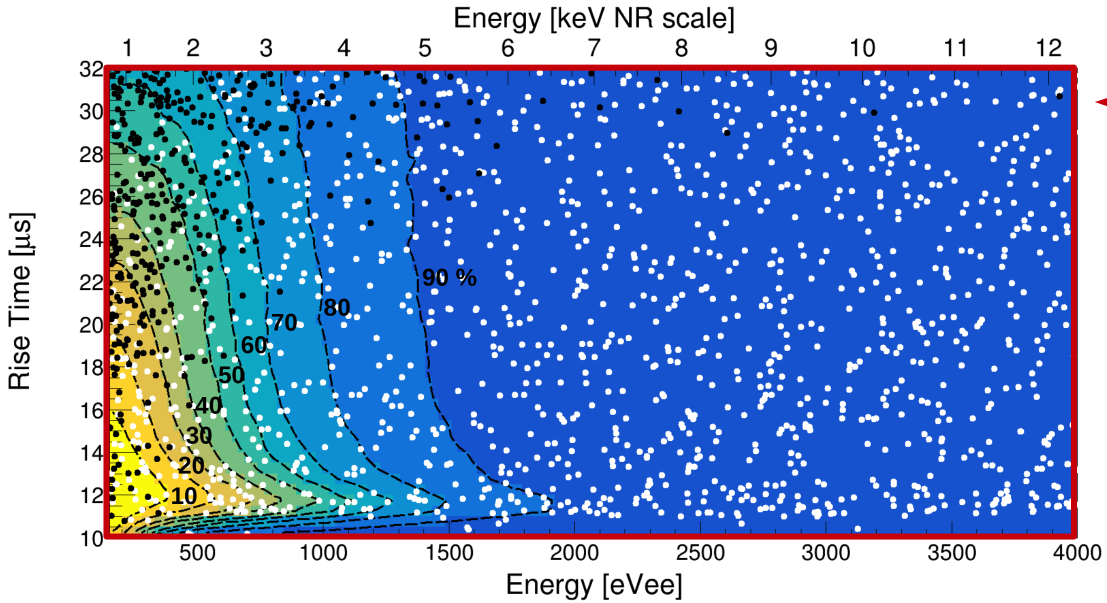
Analysis threshold set at **150 eVee**
(100% trigger efficiency)

Side Band region used to determine
The number of background events
expected in the **ROI**

~1600 events expected in the ROI ...

Need to determine a fine-tuned ROI optimized for signal/background discrimination

Optimization of the ROI



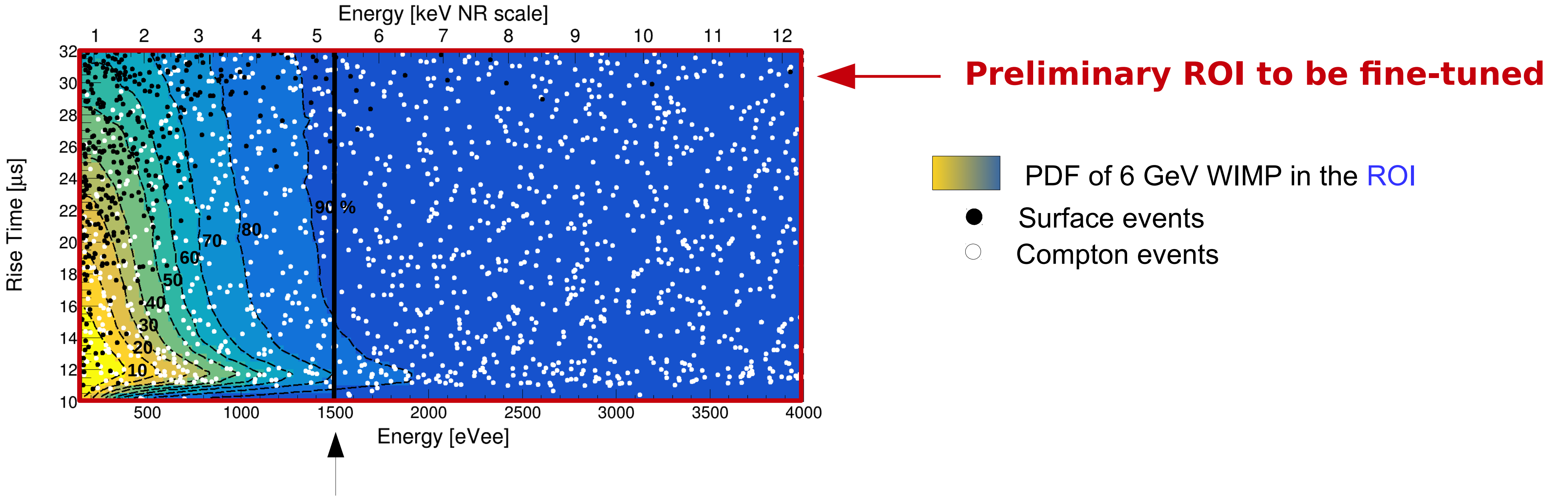
Preliminary ROI to be fine-tuned

PDF of 6 GeV WIMP in the ROI

Surface events

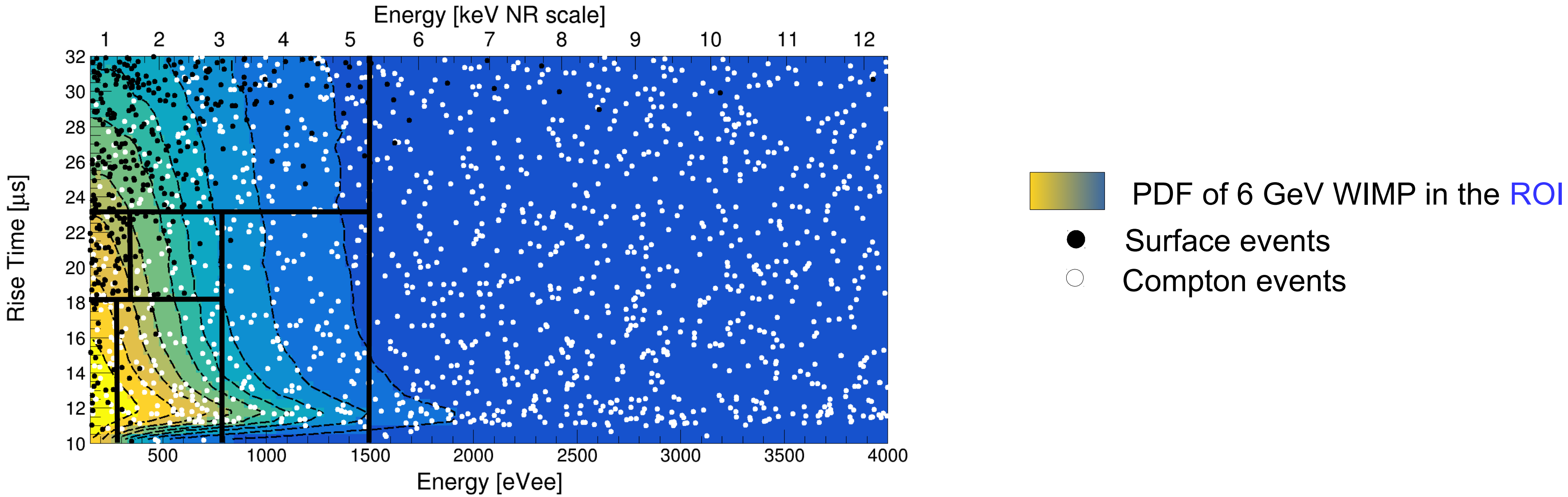
Compton events

Optimization of the ROI



With a simple cut (Energy < 1500eVee), we could get rid of a large part of the Compton background for a small price to pay of 10% signal efficiency loss

Optimization of the ROI : Boosted Decision Tree



With a simple cut (Energy < 1500eVee), we could get rid of a large part of the Compton background for a small price to pay of 10% signal efficiency loss

To determine the optimal set of cuts that will maximize our sensitivity

we use a **B**oosted **D**ecision **T**ree

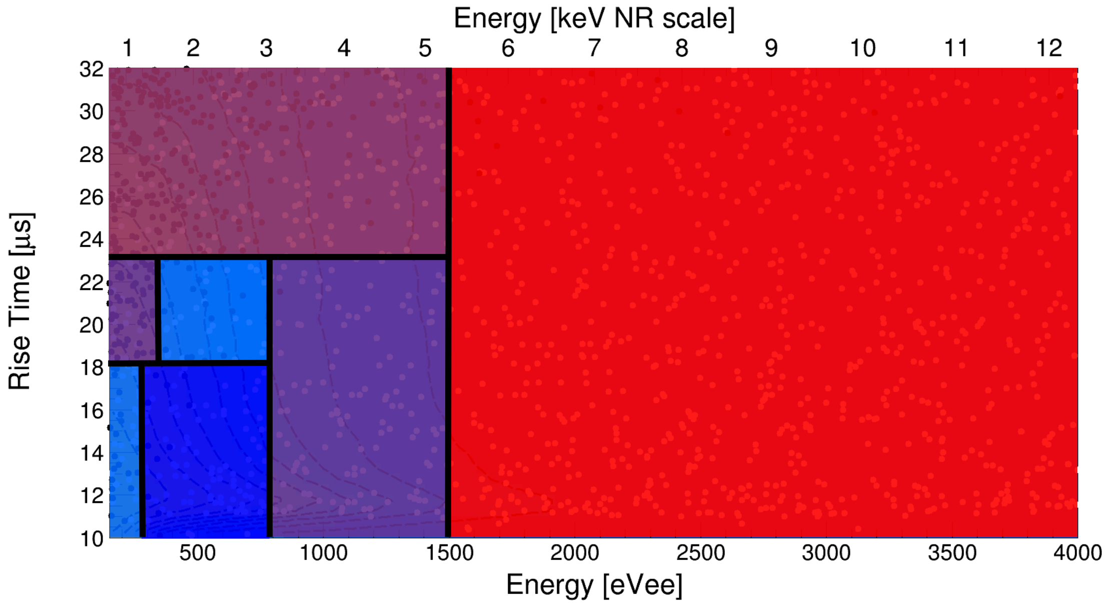
The **BDT** is trained with simulated events from our **signal** and **background** models

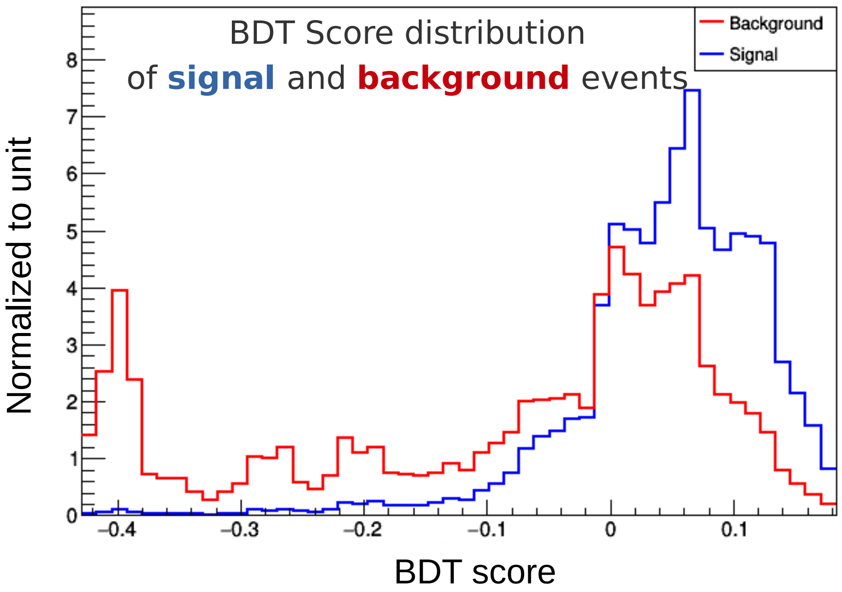
to classify events weither they are **signal-like** or **background-like**

by applying different cuts in the **Rise Time vs Energy** plane

Reduces the parameter space to only one variable : the BDT score

Optimization of the ROI : Boosted Decision Tree



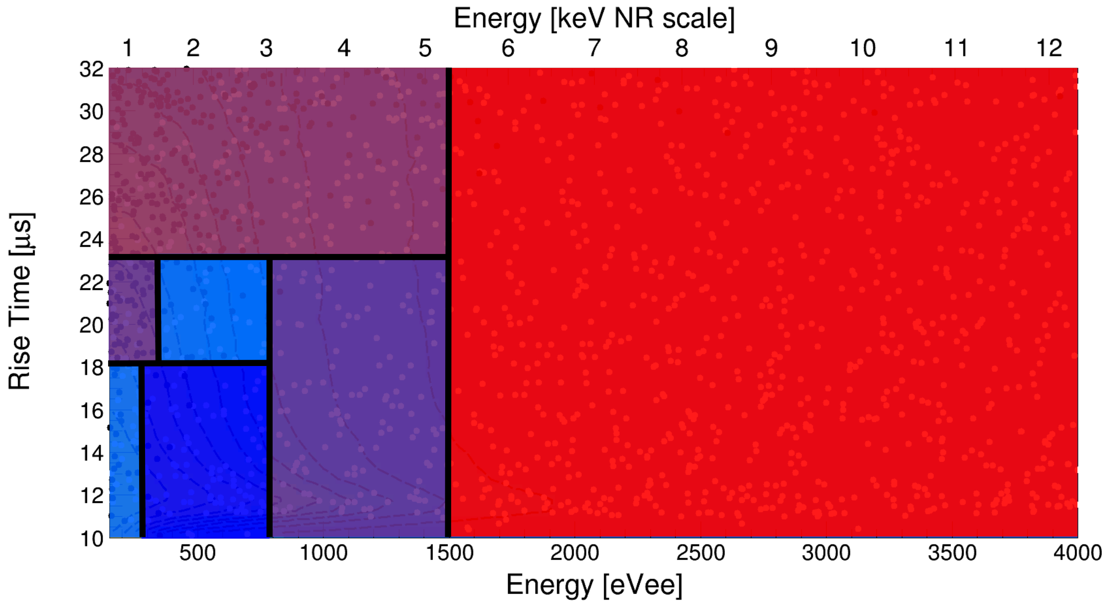


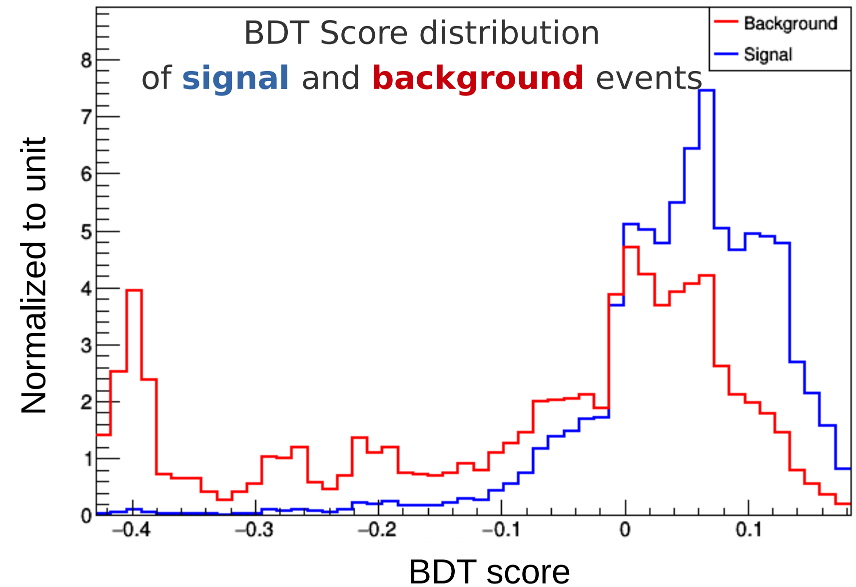
To determine the optimal set of cuts that will maximize our sensitivity
we use a **B**oosted **D**ecision **T**ree

The BDT is trained with simulated events from our **signal** and **background** models
to classify events weither they are **signal-like** or **background-like**
by applying different cuts in the **Rise Time vs Energy** plane

Reduces the parameter space to only one variable : the BDT score

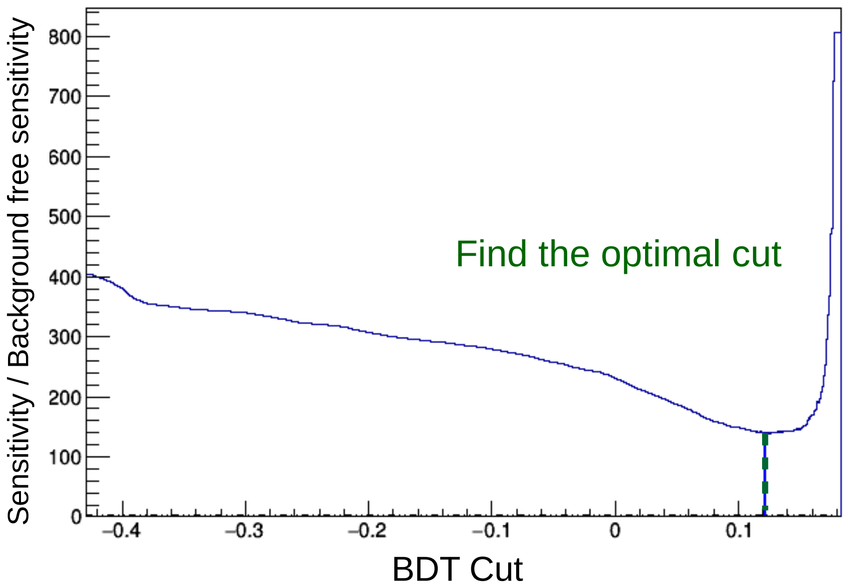
Optimization of the ROI : Boosted Decision Tree

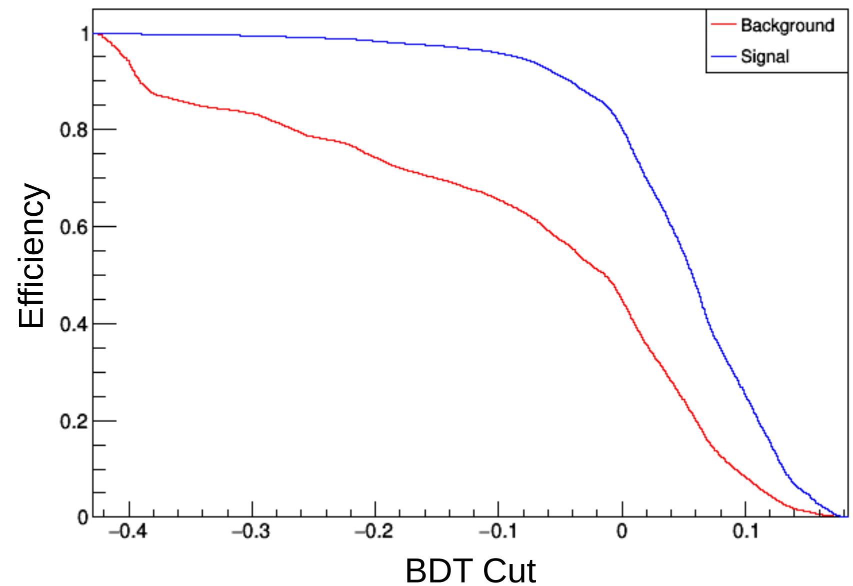




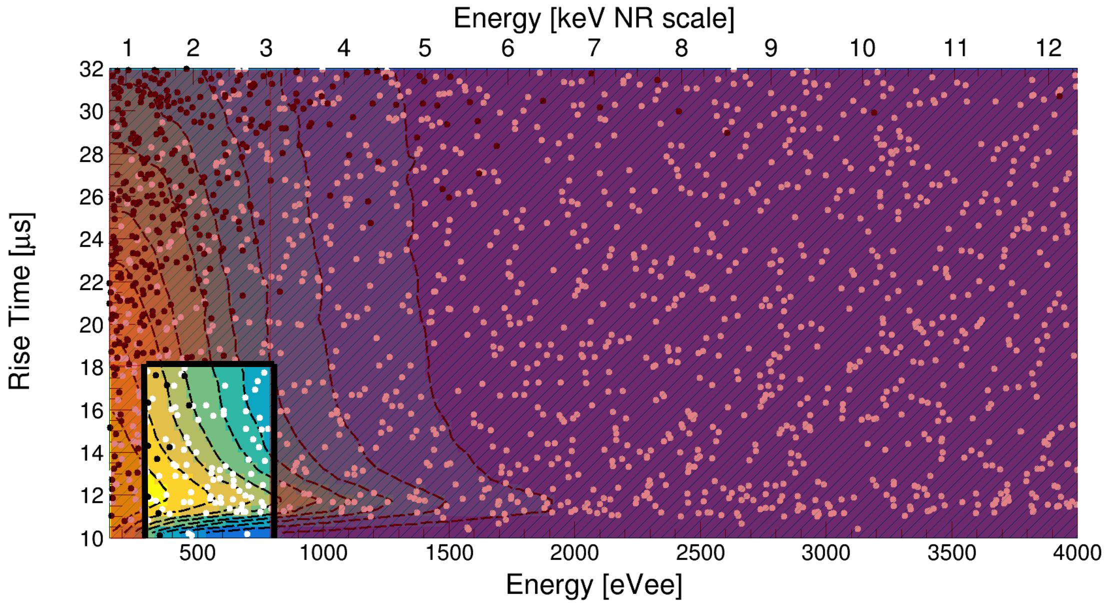
Background like
low BDT Score

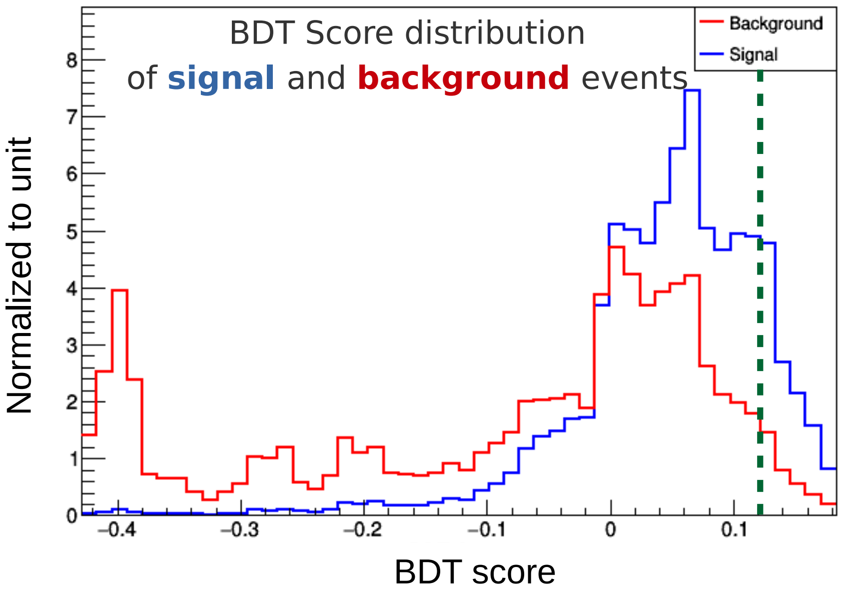
Signal like
high BDT Score



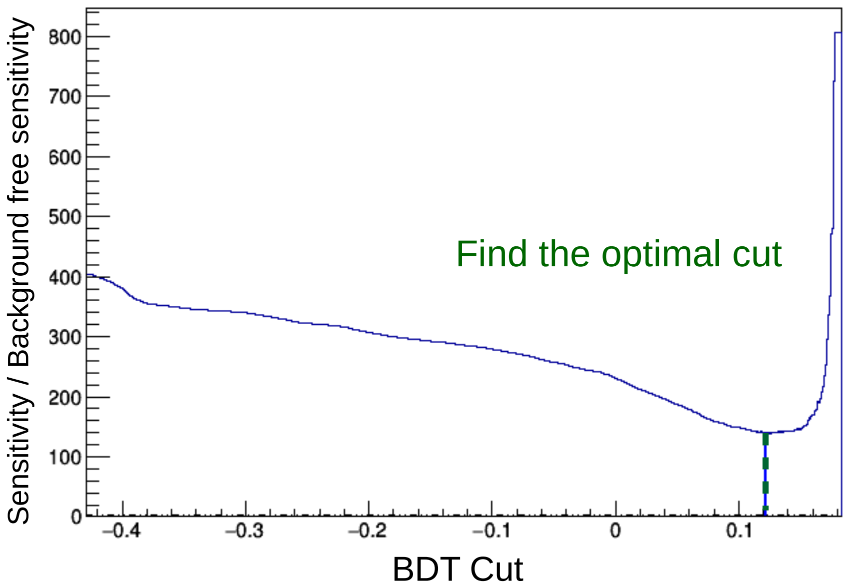


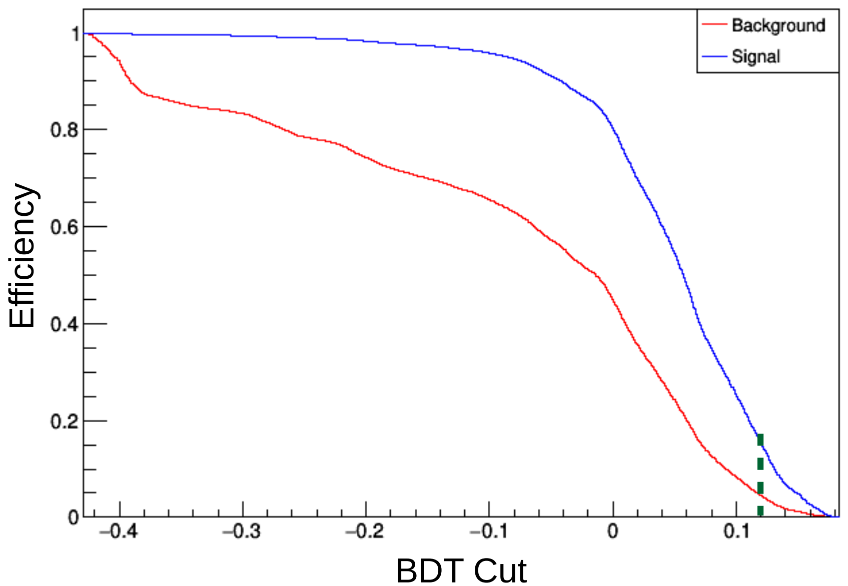
Optimization of the ROI : Boosted Decision Tree



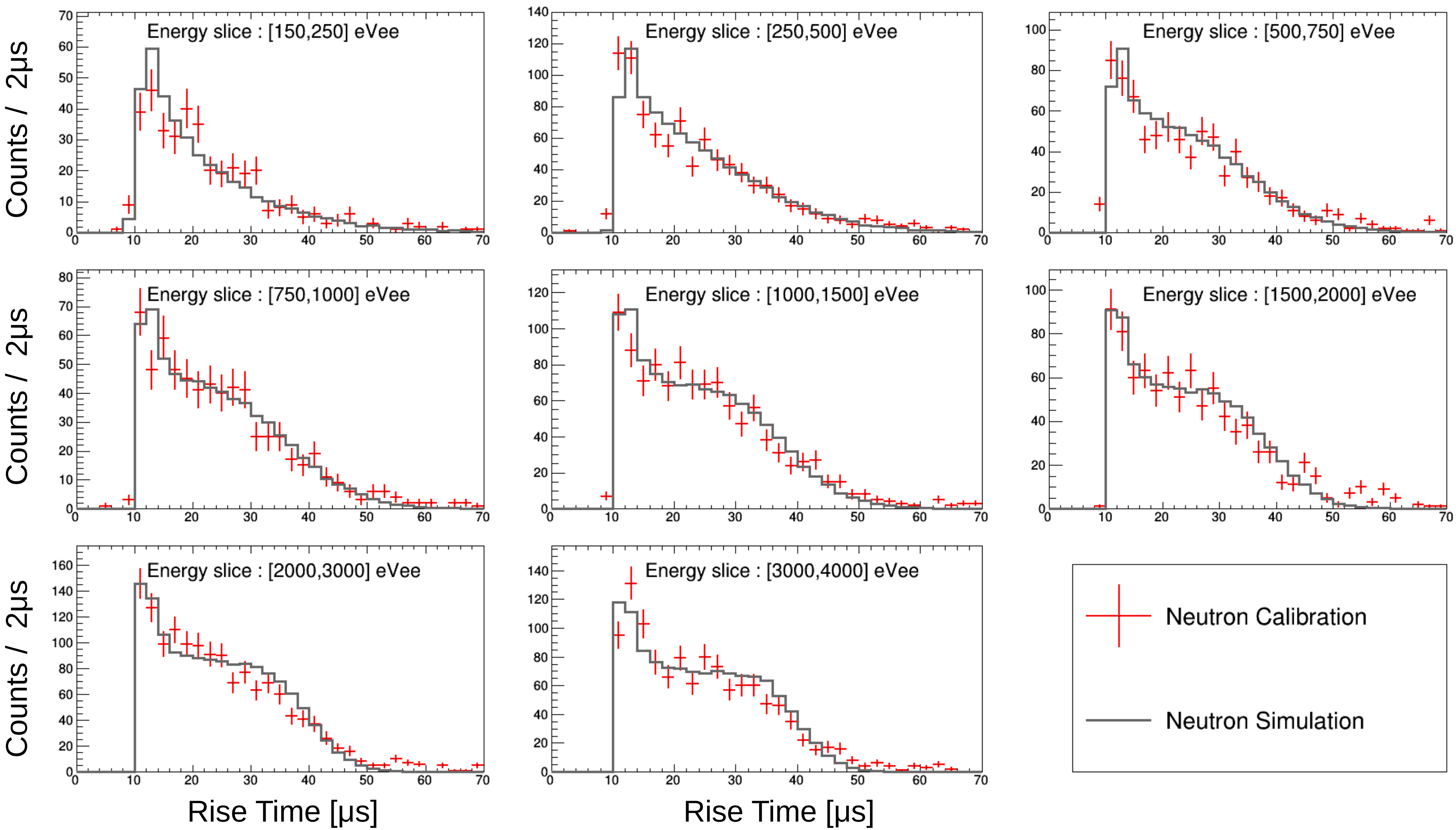


We can then perform the cut on the BDT score that optimizes the **signal** / **background** discrimination

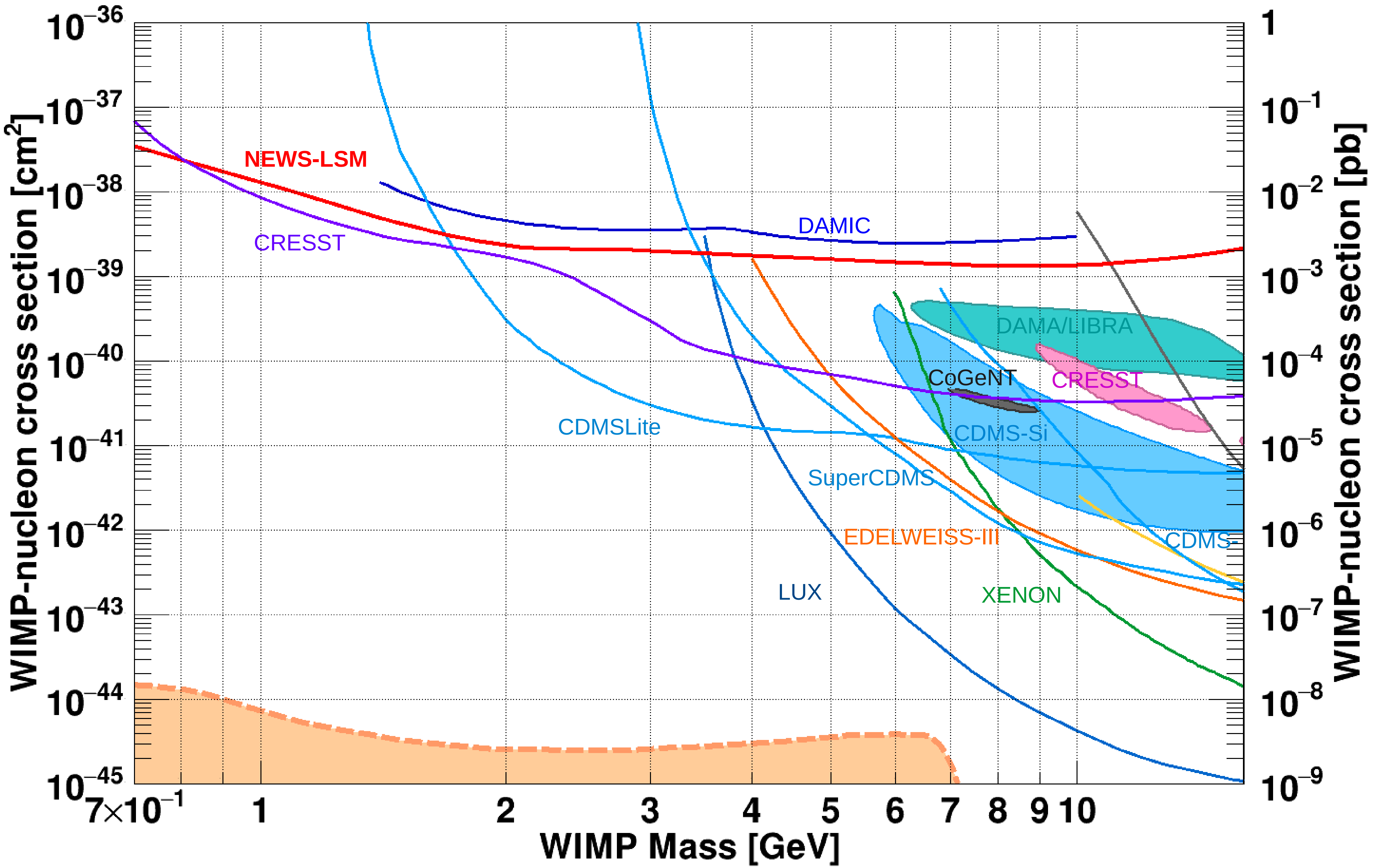




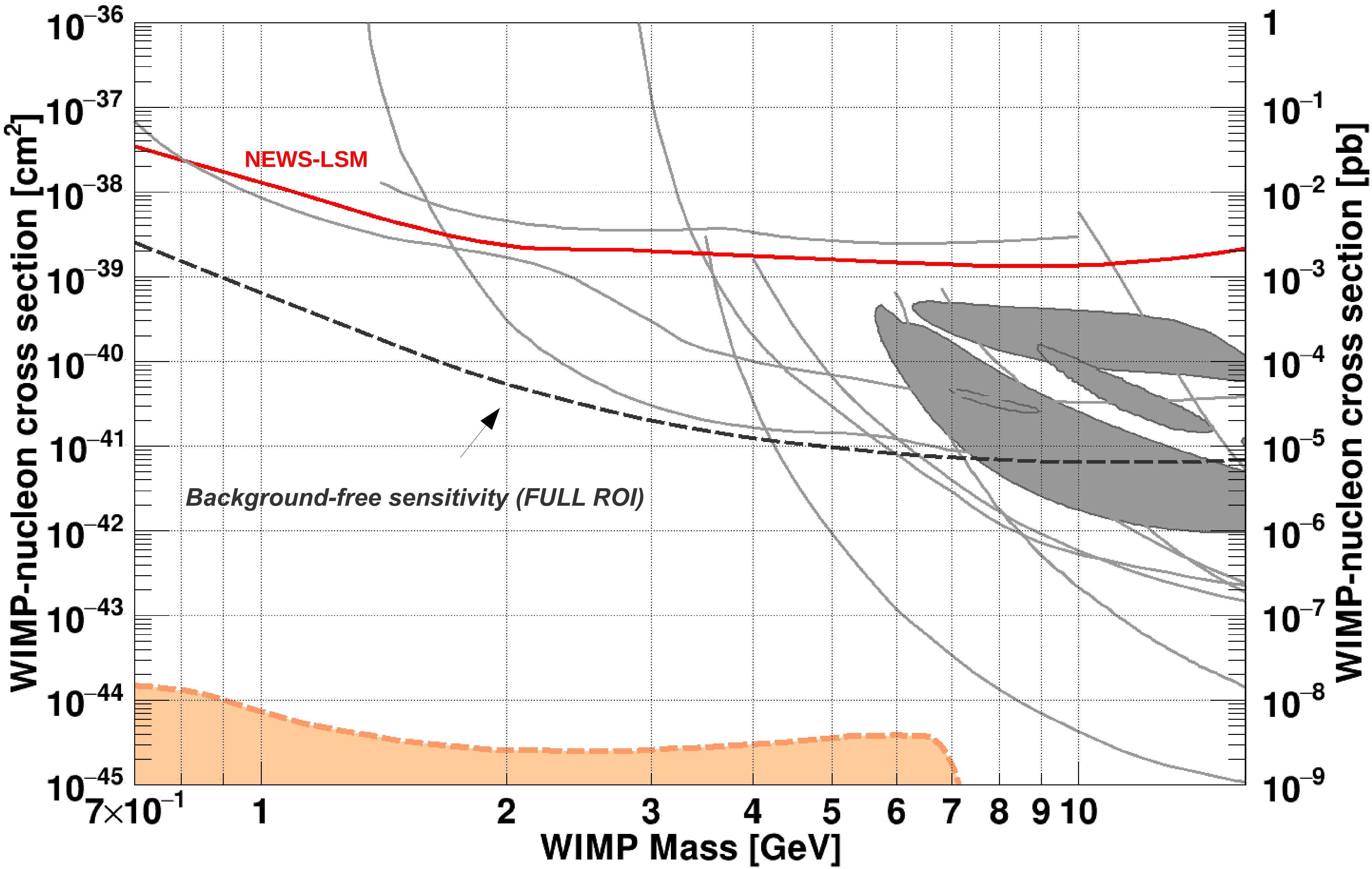
Agreement Neutron Calibration & Simulation



NEWS-LSM Results



NEWS-LSM Results



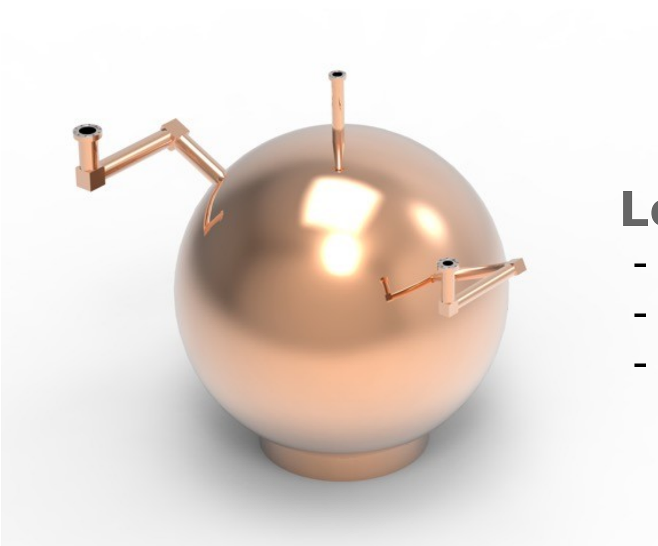
NEWS-SNO

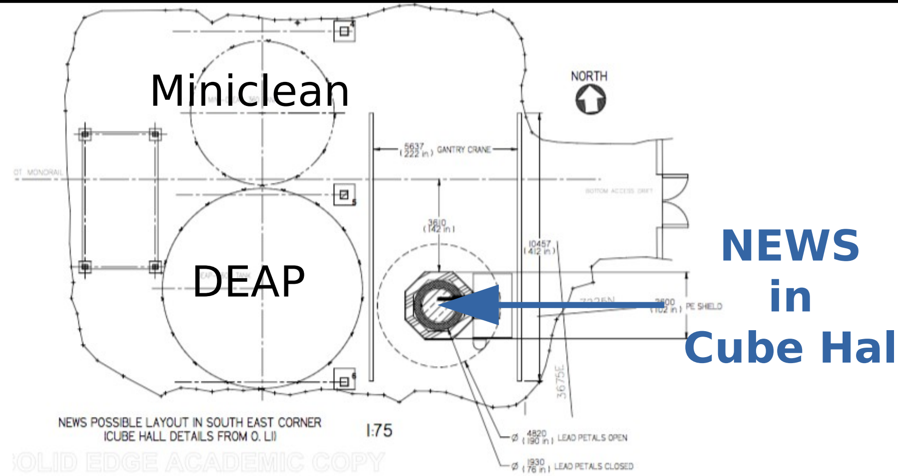
Implementation @ SNOLAB by fall 2017

140 cm Ø detector @ 10 bars (Ne, He, CH_4)

Copper vessel

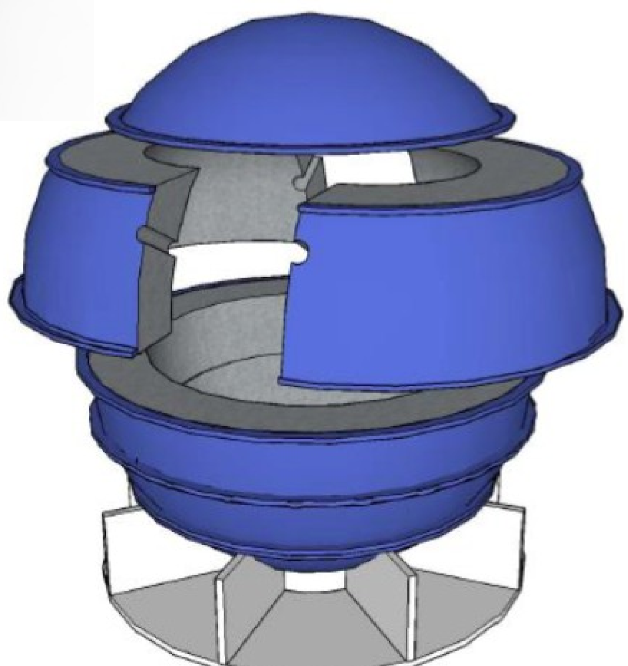
- Thickness ~12 mm

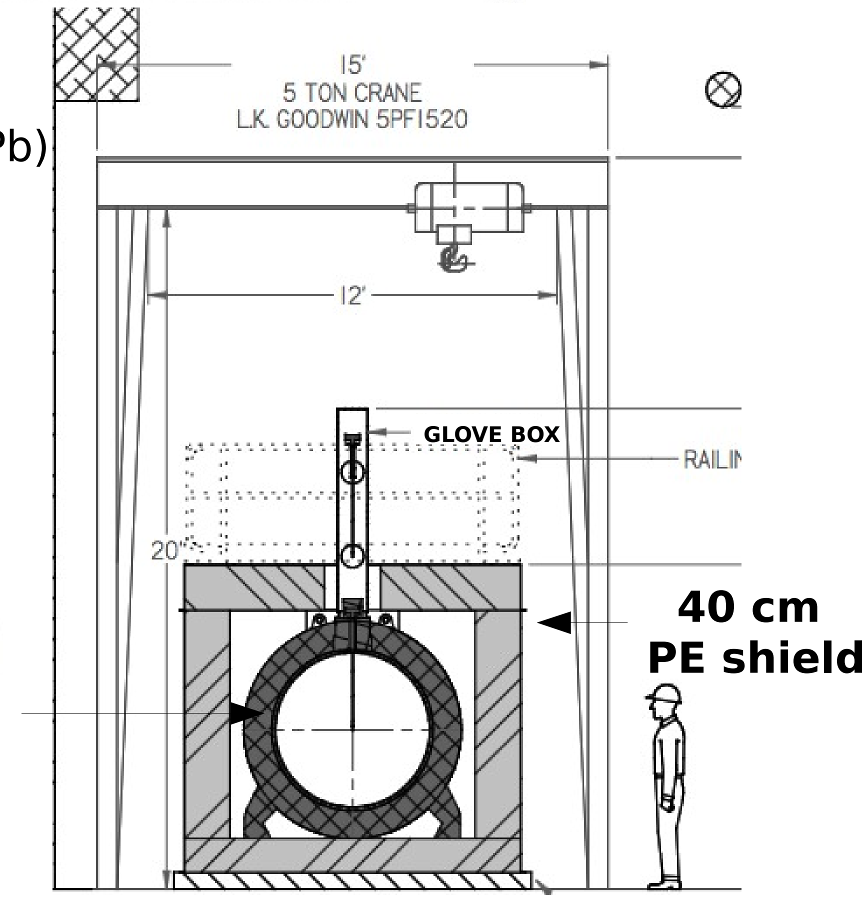




Lead shield

- 22 cm VLA (1 Bq/kg 210Pb)
- 3 cm archeological lead
- Air tight SS envelope to flush pure N





35 t shields

NEWS-SNO

Radioactive background budget	Goal / estimation / measurement	Rate Ne ev/kg.keV.d in 0-1 keV in Neon 10b	Relative weight %	Rate He ev/kg.keV.d in 0-1 keV for He/CH4-90/10	Relative weight %	Rate H ev/kg.keV.d in 0-1 keV for He/CH4-90/10	Relative weight %
U Copper	3 µBq/kg	0.017	8.2	*0.006*	*4.0*	*0.055*	*4.0*
Th Copper	13 µBq/kg	0.053	26.4	*0.004*	*3.0*	*0.041*	*3.0*
Co60 Copper	30 µBq/kg integrated exposure to CR	0.046	22.8	*0.046*	*33.2*	*0.460*	*33.2*
External radiation from rock	208Tl and 40K flux underground	0.006	3.0	*0.002*	*1.4*	*0.020*	*1.4*
U/Th from shield	U/Th in Pb shield	0.050	24.8	*0.001*	*0.7*	*0.010*	*0.7*
Radon in gas	Rn emanation within sphere/pipes/ valve (0.3 mBq)	0.005	2.5	*0.005*	*3.6*	*0.050*	*3.6*
Rod/sensor	Max 0.01 mBq	0.005	2.5	*0.005*	*3.6*	*0.050*	*3.6*
Bi210 external Surface	Assuming exposure of 4 weeks to 30 Bq/m3 Radon in air	0.001	0.5				
Pb210 internal Surface	Max exposure= 17 Bq/m3*h (100 Bq/m3 10 mins)	0.014	6.9	*0.070*	*50.5*	*0.700*	*50.5*
Pb210 in bulk from spinning inclusion	Assuming exposure of 4 weeks to 30 Bq/m3 Radon in air all going in bulk	0.005	2.5				
Total	dru	**0.202**	100.0	*0.139*	*100.0*	***1.386***	*100.0*
Nb evts in 0.2 keV	in 100 kg.d	**4.039**		***2.772***		***27.724***	

Ne He H

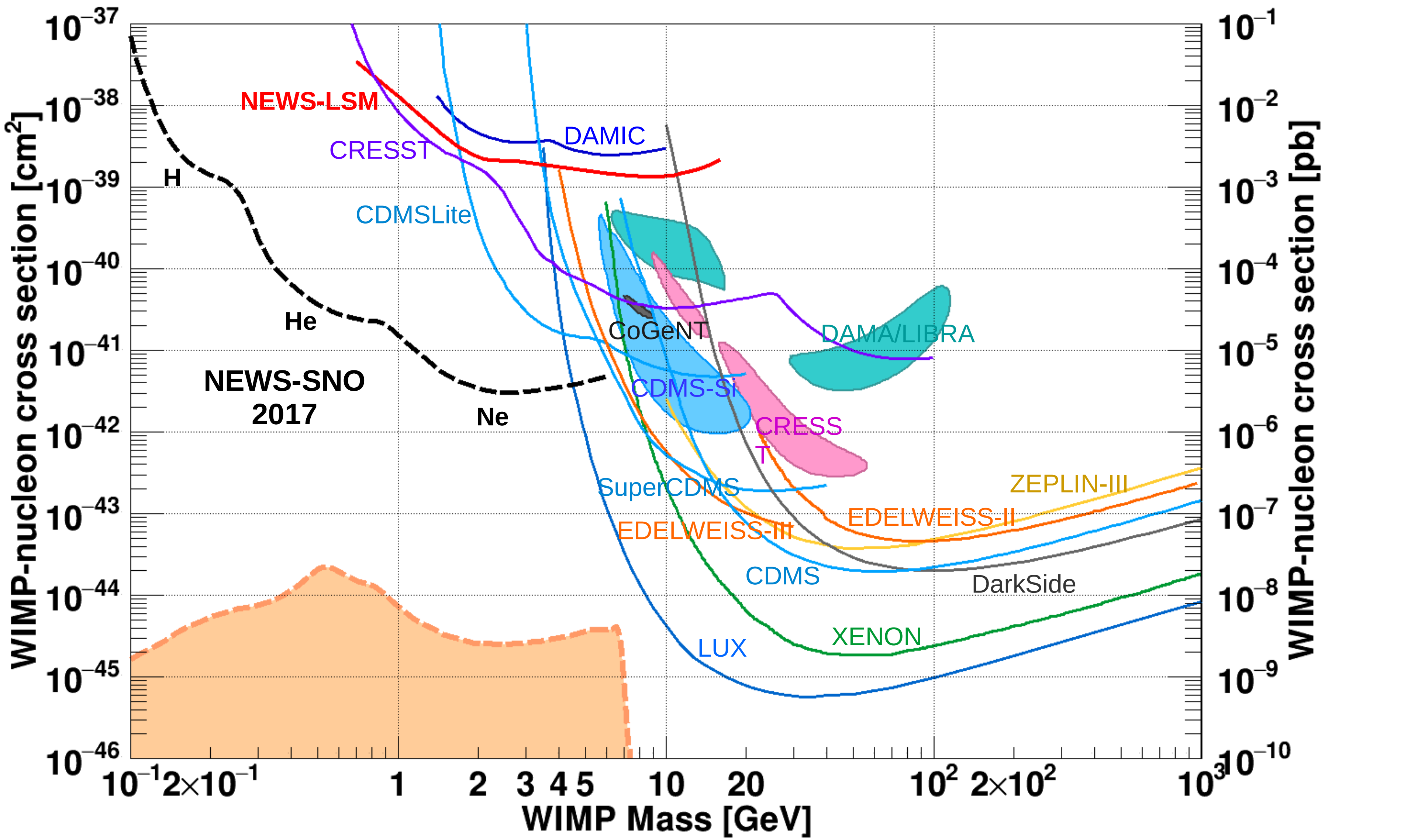
U/Th from Lead and Copper samples from spinned hemisphere measured by ICPMS at PNNL

Internal surface etching of copper vessel with HP water jet to remove Rn daughters

Electron Beam welding of all parts

2 orders of magnitude improvement of the background levels
wrt
NEWS-LSM

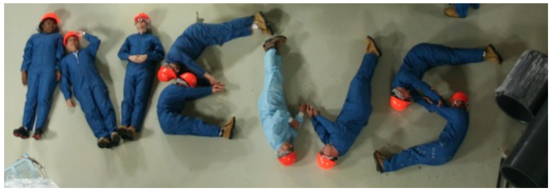
NEWS-SNO



<u>Hypothesis for NEWS-SNO expected sensitivity</u>

100 kg.days exposure @ 10 bars, Threshold set at 1 electron (~40 eVee), 200eVee window

THANK YOU



Collaboration **for your attention**

- **Queen's University Kingston –** G Gerbier, P di Stefano, R Martin, T Noble, A Brossard, A Kamaha, F Vazquez de Sola, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis
- **IRFU** (Institut de Recherches sur les Lois fondamentales de l'Univers)**/CEA Saclay** -I Giomataris, M Gros, C Nones, I Katsioulas, T Papaevangelou, JP Bard, JP Mols, XF Navick,
  - Sensor/rod (low activity, optimization with 2 electrodes)
  - Electronics (low noise preamps, digitization, stream mode)
  - DAQ/soft
- **LSM** (Laboratoire Souterrain de **Modane**), IN2P3, U of Chambéry **-** F Piquemal, M Zampaolo, A DastgheibiFard
  - Low activity archeological lead
  - Coordination for lead/PE shielding and copper sphere
- **Thessaloniki University –** I Savvidis, A Leisos, S Tzamarias, C Elefteriadis, L Anastasios
  - Simulations, neutron calibration
  - Studies on sensor
- **LPSC (**Laboratoire de Physique Subatomique et Cosmologie) **Grenoble** - D Santos, JF Muraz, O Guillaudin
  - Quenching factor measurements at low energy with ion beams
- **Technical University Munich –** A Ulrich, T Dandl
  - Gas properties, ionization and scintillation process in gaz
- **Pacific National Northwest Lab–** E Hoppe, DM Asner
  - Low activity measurements, Copper electroforming
- **RMCC (**Royal Military College Canada**) Kingston –** D Kelly, E Corcoran
  - 37 Ar source production, sample analysis
- **SNOLAB –Sudbury –** P Gorel
  - Calibration system/slow control

- **Associated lab : TRIUMF - F** Retiere
  - Future R&D on light detection, sensor